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CONDENSED MILK
AND
MILK POWDER

CONDENSED MILK
AND
MILK POWDER

PREPARED FOR
FACTORY, SCHOOL AND LABORATORY

FIFTH EDITIO
REWRITTEN AND ENLARGED

BY
OTTO FREDERICK HUNZIKER
B.S.A., M.S., D.Sc.

PUBLISHED BY THE AUTHOR
LA GRANGE, ILLINOIS
(1935)

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TO THE MEMORY

of

MY FATHER

This Volume Is Dedicated

ACKNOWLEDGMENTS

In presenting this volume to the Dairy Industry, the author desires to express his grateful appreciation to

Mr. A. W. Baumann, Development Engineer of Arthur Harris & Co., Chicago, for valuable information and advice on vacuum pan construction, thermodynamics and steam requirements for condensing, for his generous contribution of knowledge regarding the latest commercial developments of the industry and for the preparation of numerous mechanical drawings illustrated in this volume;

Mr. W. A. Cordes, in charge of the Research Laboratories of the Blue Valley Creamery Company, Chicago, for his generous contribution of assembling the Bacteriological Methods of Analysis presented in this volume;

Mr. A. J. Ihde, Chemist of the Blue Valley Creamery Co. Research Laboratories, for many helpful suggestions on the chemical phases of the subject;

Mr. George W. Putnam, Director of Research, Creamery Package Mfg. Co., Chicago, for concrete information on evaporated milk irradiation.

Dr. George Spitzer, Professor of Dairy Chemistry, Purdue University, Lafayette, Indiana, for valuable advice relating to the science of enzyme reactions;

I am greatly indebted also to the many individuals and firms who offered their generous co-operation in the form of additional information on specific phases of the subject, who supplied valuable illustrations for the text and who honored this publication with their esteemed advertisements.

PREFACE

In preparing the "Fifth" edition of "Condensed Milk and Milk Powder" it has been the author's endeavor to present to the interested reader and to the dairy industry his own experience and the experiences of others who are in intimate touch with this branch of the industry, together with the latest available knowledge pertaining to the science and practice of the manufacture of concentrated and dried milk products.

No effort has been spared in this earnest endeavor to digest this information and to present it in a manner readily assimilable by those seeking knowledge or who are in need of assistance in the solution of their daily problems.

It is the author's cherished hope that this new volume may fulfill its purpose of usefulness and service to all who are interested in the subject.

O. F. HUNZIKER.

Chicago, Ill., October, 1934.

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PART I

Condensed Milk

CHAPTER I

DEFINITION, HISTORY AND DEVELOPMENT ANNUAL PRODUCTION

DEFINITION

Condensed milk is cow's fresh milk from which a considerable portion of the water has been evaporated and to which sucrose or dextrose may or may not have been added.

There are chiefly two classes of condensed milk, namely, sweetened and unsweetened. Both reach the market in hermetically sealed tin cans intended for direct consumption, and in bulk, intended for bakers, confectioners and ice cream manufacturers.

A portion of the condensed milk on the market is made from the chief by-products of milk, skim milk and buttermilk. Condensed skim milk supplies the same markets as condensed whole milk sold in bulk. Condensed buttermilk furnishes a valuable hog and chicken feed. It has, also, been recommended for medicinal purposes, and of late years it has found extensive use in bakeries and for the manufacture of diverse prepared foods.

Condensed milk is sold under several specific trade names according to process of manufacture and composition. Thus,

Sweetened Condensed Milk is condensed milk containing added sucrose, or dextrose, or both.

Evaporated Milk is condensed milk to which no extraneous sugar has been added and which has been sterilized in hermetically sealed cans.

Plain Condensed Milk is condensed milk containing no added sugar and which reaches the market unsterilized.

Evaporated Cream is condensed cream containing no added sugar and which has been sterilized in hermetically sealed cans.

Sterilized Sweet Cream is uncondensed cream, containing no added sugar and which has been sterilized in hermetically sealed cans.

Sweetened Condensed Skimmilk is condensed skimmilk containing added sucrose, or dextrose, or both.

Plain Condensed Skimmilk is condensed skimmilk without added sugar and which has not been sterilized.

Evaporated Skimmilk is condensed skimmilk containing no added sugar, and which has been sterilized in hermetically sealed cans.

Semi-Solid Buttermilk is condensed buttermilk containing no added sucrose and which has not been sterilized.

HISTORY AND DEVELOPMENT OF INDUSTRY

Invention of Process.—Condensed milk is the child of the nineteenth century. Its origin does not date back far, and its innovation and rapid development stand in sharp contrast to those of the manufacture of butter and cheese, industries to which reference is made in the Old Testament* and the evolution of which has been very gradual. Notwithstanding the newness of this product, its manufacture has assumed such proportions that today it occupies a prominent place among the leading branches of dairy manufactures.

The condensed milk industry was introduced at about the same time as the factory system of the butter and cheese industry; although, for many years before the invention of a successful process of condensing milk, methods had been sought to preserve milk.

It was especially during the first half of the 19th century that food scientists of France and England gave thought to the possibilities of preserving milk in concentrated form. Thanks to the several editions of the publication on Preservation of Foods by the French research worker Nicolas Appert, information is available regarding the earliest attempts at milk condensing. As early as 1811 Appert made milk tablets and later experimented on methods of concentrating milk and preserving it by the application of heat. De Heine received an English patent in 1810 on his method of heating milk in an open vessel and preserving it by the addition of sugar. The Frenchman, Malbec, concentrated milk with sugar in 1826, and the American, William Underwood, prepared milk with sugar and bottled it in 1828. The vacuum pan was invented by Edward Charles Howard, England, and patented in 1813, but it was the Englishman, Wm. Newton, who adapted its use to milk, on the process of which he was granted a British patent in 1835. The Frenchman, Martin de Lignac, received a British patent on a process of evaporating milk and preserving it with sugar in 1847, and Grunaud and Galais marketed milk, in bottles, that had been condensed to a concentration of 4 to 1 at a temperature not exceeding 30°C. (86°F.).

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*Book of Genesis, C. 18, V. 8: "And he took butter and milk and the calf he had dressed and set it before them."

Book of Job, C. 10, V. 10: "Hast thou not poured me out like milk and curdled me like cheese."

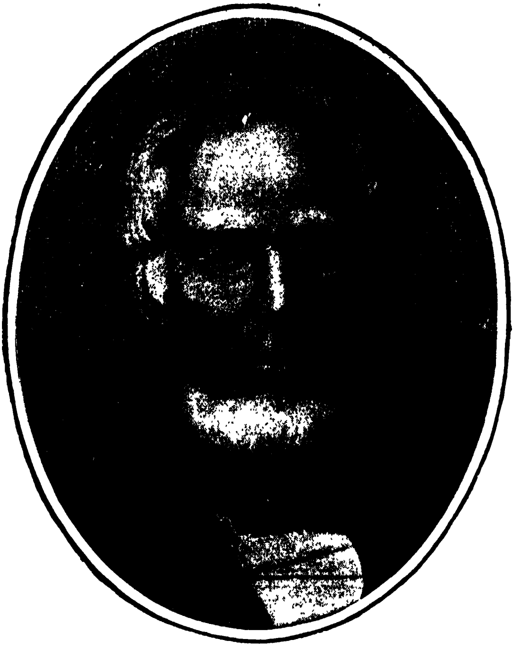

Fig. 1. Gail Borden

The commercially successful manufacture of condensed milk was initiated by the American, Gail Borden. He is the inventor of the process of milk condensing upon which a great and successful industry has been builded. Gail Borden is said to have experimented some ten years before he finally decided that a semi-fluid state, produced by evaporation in vacuo, was the best form of preservation. He first applied for a patent in 1853, but it was not until three years later that the Patent Office appreciated the originality and value of his claim sufficiently to grant him a patent. In August, 1856, he received a patent both from the United States and from England. In his application Mr. Borden[1] says:

"I am aware that sugar, and various extracts, have been and are now concentrated in vacuo under a low degree of heat, to prevent discoloration or burning. I do not claim concentrating milk in a vacuum pan for such a purpose, my object being to exclude the air from the beginning of the process to the end, to prevent incipient decomposition. This is important and I claim the discovery."

The claim, United States Patent No. 15,553, August 19, 1856, is in the following words:

"Producing concentrated sweet milk by evaporation in vacuo, substantially as set forth,—the same having no sugar or other foreign matter mixed with it."

Since the introduction of the process of milk condensing, invented and patented by Borden, numerous modifications of the process, as well as entirely different processes, have been invented in this country and abroad. The most characteristic among these are:—condensation by refrigeration, by centrifugal force, by boiling under atmospheric pressure, by passing hot air over or through milk, etc. Most of these new processes have not proved commercially satisfactory, with the result that the principle of the process, originally invented by Gail Borden, and which consists of condensing the milk in vacuo to a semi-fluid liquid, is still made use of in the manufacture of the great bulk of condensed milk produced, both in this country and abroad.

While the claim of the patent granted Gail Borden was that of "producing concentrated sweet milk by evaporation in vacuo without the admixture of sugar or other foreign matter," records show that Gail Borden manufactured sweetened condensed milk, sold under the famous Eagle Brand label as early as 1856. The first advertisement by Borden of unsweetened condensed milk was recorded in Leslie's Weekly, May 22, 1858. It reads as follows:

"Borden's Condensed Milk. Prepared in Litchfield County, Conn., is the only milk ever concentrated without the admixture of sugar or some other substance and remaining easily soluble in water. It is simply Fresh Country Milk from which the water is nearly all evaporated, and nothing added. The Committee of the Academy of Medicine recommend it as an article, that, for purity, durability and economy, is hitherto unequalled in the annals of the milk trade.

"One quart, by the addition of water, makes two and a half quarts,—equal of cream, five quarts rich milk and seven quarts good milk.

"For sale at 173 Canal Street, or delivered at dwellings in New York or Brooklyn at 25 cents per quart."

Development of Industry.—The beginning was small, the process crude and the product imperfect. Not until the strenuous years of the war of Secession did the value and usefulness of condensed milk as a commodity become fully recognized. During the Civil War there was a great demand for this product and from that time on the industry grew with great rapidity.

The first factory was operated by Gail Borden in Wolcottville, Litchfield County, Connecticut, in the summer of 1856, but disappointed in not obtaining means, nothing was accomplished. A second attempt was made at Burrville, five miles distant, in 1857, by a company consisting of the owners of the patent. A small quantity of milk was here successfully condensed and its introduction into New York began. Although admitted by all to be superior to any before made, it was slow in meeting with sales proportional in magnitude to the expenses incurred. Yielding to the monetary revulsion of that year the company suspended operations, leaving Mr. Borden liable for bills drawn, on which he was sued.

It was not until February 1858, when Mr. Borden (with the other owners of the patent) associated himself with Jeremiah Milbank, Esq., who advanced money to revive the business, that he could be said to enjoy adequate means to develop his invention and at which time the New York Condensed Milk Company was formed. Abandoning Burrville, the new company established work on a more extensive scale in Wassaic, Duchess County, New York, in 1860. In 1865, extensive works were erected at

Fig. 2. The first condensery in America, Wolcottville, Conn.

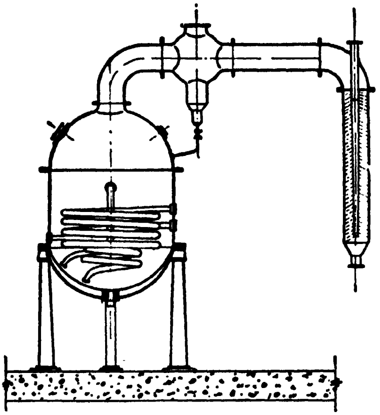

Fig. 3. The first vacuum pan of the Anglo-Swiss Condensed Milk Co., Cham, Switzerland

Elgin, Illinois. Borden's Condensed Milk factories today number upwards of fifty, extending from Maine to Washington State as well as into Canada. The New York Condensed Milk Company was incorporated in New Jersey in 1860 and in New York in 1870. This company was succeeded by Borden's Condensed Milk Company which was incorporated in New Jersey in 1899.

In the sixties of the last century, the Anglo-Swiss Condensed Milk Company was organized in Switzerland under the leadership of Charles A. Page, then United States Consul at Zurich, Switzerland, and his brother George H. Page, and with the assistance of Swiss and English capital. The first factory of that company was built and operated in 1866 at Cham, Lake Zug, Switzerland, under the direction of George H. Page, who was its president until 1898, when he died.

This company prospered and grew rapidly in Europe. In the eighties of the last century it invaded the United States, where it built and operated several large factories in New York, Wisconsin and Illinois. The American factories were managed by David Page and William B. Page, brothers of George H. Page. In 1902 the Anglo-Swiss Condensed Milk Company sold its entire American interests, factories and business, to Borden's Condensed Milk Company. In 1904 the Anglo-Swiss Condensed Milk Company consolidated with Henry Nestle, of Vevey, Lake Geneva, Switzerland, another successful manufacturer of condensed milk. The company which is now known as the Nestle-

Anglo-Swiss Condensed Milk Company, is operating some twenty large condensed milk factories with headquarters at Vevey, Switzerland. The majority of these factories are located in European countries. One very large plant is situated in the state of Victoria, Australia.

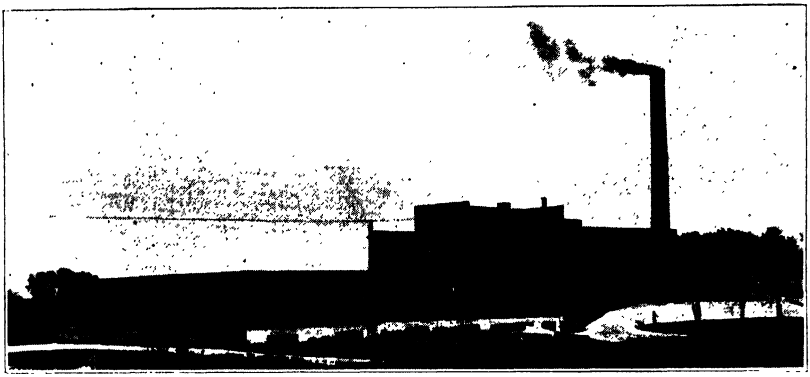

Fig. 4. A modern milk condensery
Courtesy of the Page Milk Co., Merrill, Wis.

Up to the early eighties of the last century, sweetened condensed milk was the only condensed milk that was put on the market and sold in hermetically sealed cans, while unsweetened condensed milk was manufactured and sold open, largely direct to the consumer, in a similar way as market milk. The purity and keeping quality of this unsweetened condensed milk, however, were greatly superior to market milk.

Early in 1885 the Helvetia Milk Condensing Company was organized at Highland, Illinois. This company confined its efforts exclusively to the manufacture of evaporated milk (unsweetened condensed milk, sterilized by heat and sold in hermetically sealed cans). While, for several years before the organization of this company, the possibilities of producing a sterile unsweetened condensed milk were essayed in laboratory investigations by scientists, and while simultaneously with the commencement of operations of this company, several other companies experimented on this form of condensed milk, the Helvetia Milk Condensing Company was the first organization that succeeded in producing a marketable unsweetened condensed milk that was sterile and would keep indefinitely.

The basic principle of the process of preserving unsweetened condensed milk by heat sterilization was introduced by Mr. John B. Meyenberg,[2] a native of Switzerland, born Nov. 13, 1847, in Zug, Switzerland. Mr. Meyenberg was operator in the mother plant of the Anglo-Swiss Condensed Milk Company at Cham, Switzerland, where he conceived the idea of making condensed milk keep without the addition of cane sugar, or other preservatives and without the necessity of keeping it cold.

Fig. 5. John B. Meyenberg

Being of an inventive turn of mind, Mr. Meyenberg experimented on the sterilization of condensed milk by steam under pressure over a period of three years, 1880 to 1883. As the result of these experiments, he decided that it was possible to preserve milk without the aid of sugar, by the use of a revolving sterilizer which he designed.

Migrating to this country in 1884, he was granted in the same year a basic patent on his invention of a sterilizer, U. S. Patent Number 308,421 and patents on his process of preserving milk, U. S. Patent Numbers 308,422 (1884) and 358,213 (1887).

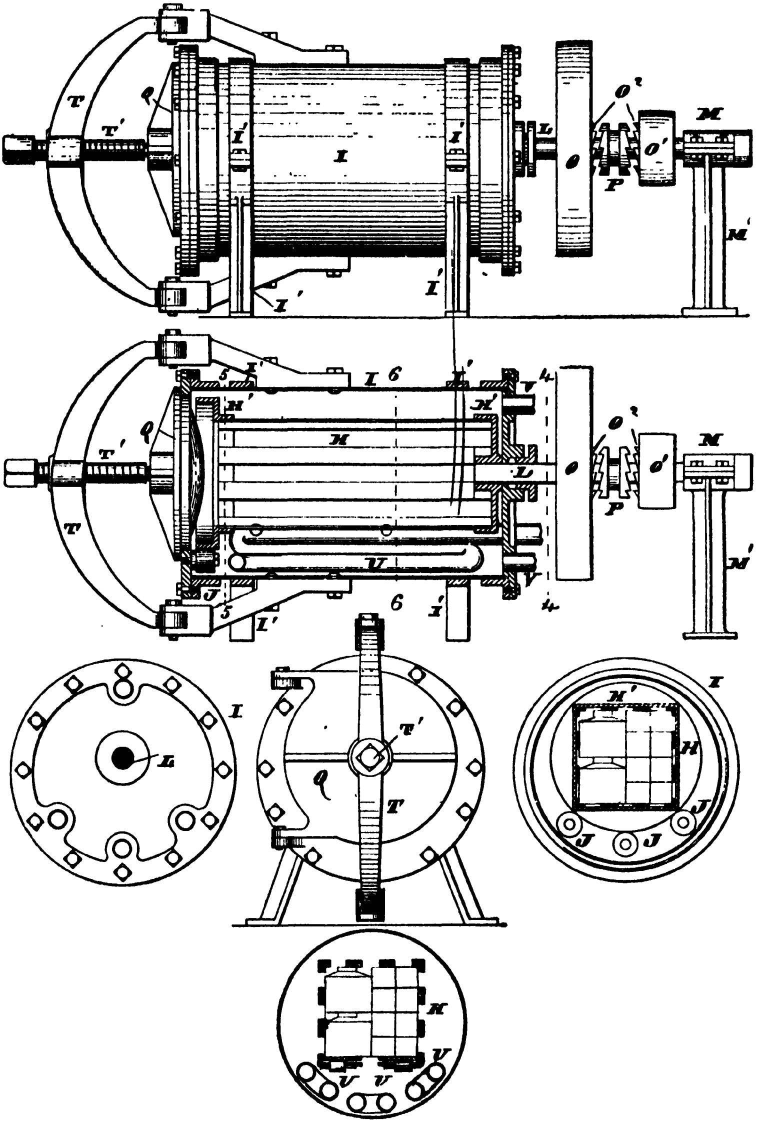

Fig. 6. Meyenberg sterilizer **U. S. Patent No. 308,421**
Courtesy of Meyenberg All Pure Milk Co.

The original Meyenberg sterilizer is shown in patent drawing Fig. 6, which is accompanied by the following claims:

"I claim as my invention—

"1. The combination of the revolving frame adapted to receive cans, the outer inclosing cylinder, and the air and steam pipes, arranged and operating substantially as and for the purpose set forth.

"2. The combination of the revolving frame H, cylinder I, surrounding the frame, steam pipes U within the cylinder beneath the frame, air pipes entering one end of the cylinder, and a door at the other end of the cylinder, through which the frame passes as set forth."

Mr. Meyenberg's process patents provide sterilization by steam under pressure at a temperature not to exceed 240° F. while the cans are continuously agitated by the revolving reel.

Attracted to Highland, Illinois, by reason of its large Swiss population, on the representations of Mr. A. J. Pagan, a leading Highland citizen, who brought Mr. Meyenberg to Highland and introduced him to the community, Mr. Meyenberg associated himself with Mr. John Wildi, then a merchant of Highland, who at once took a leading part in the organization of the Helvetia Milk Condensing Company, early in the year 1885.

Evaporated milk was first packed in this country on a successful basis under the Meyenberg process on June 15, 1885, at Highland, Illinois.

After serving as technical manager at the Highland factory in 1885, Mr. Meyenberg severed his connections with the Helvetia Milk Condensing Company and became engaged in the promotion of numerous factories in the middle west and on the Pacific Coast. Mr. Meyenberg died October 27, 1914.

During the first year of its existence, operations of the Helvetia Milk Condensing Company were suspended a number of times both on account of difficulties encountered in the technique of successful manufacture and also for financial reasons. In an endeavor to place the company on a technically and commercially successful basis, the board of directors took charge of the work with Mr. Louis Latzer as technical manager, and the first half of the second year was mostly devoted to experimental work. During the third year, interruptions in the operations were only slight and after that the company operated continuously and successfully until the panic of 1893, which marked the last suspension of business and which was due to the strained commercial conditions that prevailed throughout the country.

The first board of directors of this company was composed of Dr. Knoebel, John Wildi, George Roth, Fred Kaeser and Louis Latzer, with Dr. Knoebel as president and Mr. Wildi as secretary, treasurer, and business manager. In 1888 Mr. Latzer became president, which position he held till his death in 1924. In 1907 Mr. Wildi severed his connection and organized the John Wildi Evaporated Milk Company with headquarters in Columbus, Ohio. Mr. Wildi died in 1910.

The early development and the vicissitudes through which this pioneer company in the evaporated milk business passed are most instructively expressed by its late president, Mr. Latzer[3]:

"Very little of the product turned out the first two years would now pass as standard goods. About the third year, after more knowledge of the physical and chemical properties of milk and after the introduction of the practice of fractional sterilization, had solved the keeping properties and had improved the physical condition of the product, we felt that the industry had come to stay. After we had gained more knowledge and experience, and a lower standard of the product was adopted by the industry, the practice of fractional sterilization was abandoned for economic reasons.

"The commercial part of the business also had its trials and tribulations in introducing a new and comparatively inferior product of comparatively high cost, and to overcome the prejudices of both the trade and the medical profession.

"The problem thus confronting the company was to improve the product, decrease its cost and improve selling methods at the least possible cost."

At first this unsweetened condensed milk, of relatively thin consistency and pregnant with the cooked flavor resulting from its exposure to high sterilizing temperatures, failed to appeal to the public, who had become accustomed to the use of the sweet, thick and semi-fluid sweetened condensed milk. But of late years the demand for, and the manufacture of this product, evaporated milk, has increased rapidly, until today, in this country, its output by far exceeds that of sweetened condensed milk.

Originally this unsweetened sterilized condensed milk was labled and sold under the name of "Evaporated Cream." The Federal Food and Drugs Act of 1906 caused the name "Evaporated Cream" to be changed to "Evaporated Milk."

The fundamental equipment used in the early days of the industry has not materially changed in principle. Condensing is still largely done in the vacuum pan under the Gail Borden process and sterilizing is done by steam under pressure in sterilizers embracing the principles introduced by Mr. Meyenberg. Yet there has been marked development and improvement of the original type of equipment used. The diligent application of the sciences of mechanical engineering and of thermodynamics has wrought such changes in the construction of vacuum pans and arrangement of heating surface and condenser, as to accelerate evaporation and make possible greater economy of condensing. The sterilizing equipment also has undergone changes that make for more economical handling of the tins and greater uniformity of results. These improvements are discussed in detail under

Table 1.—Annual Production of Condensed Milk in the United States*

Year	Total	Sweetened		Unsweetened	
		Skimmed (in barrels)	Unskimmed (in tins)	Skimmed[1]	Unskimmed[2]
	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds
1899	186,921	x	x	x	x
1904	308,485		198,355[a]		110,,129[a]
1909	494,796		214,518[a]		280 278[a]
1914	883,112	x	x	x	x
1917	975,000	x	x	x	x
1918	1,674,898	55,333	446,418	60,473	1,112,673
1919	2,030,957	72,844	611,637	74,665	1,272,010
1920	1,578,015	69,911	363,915	70,625	1,052,347
1921	1,464,163	69,911	222,308	70,625	1,101,317
1922	1,431,349	79,964	260,748	70,640	1,019,997
1923	1,774,881	104,984	240,918	84,451	1,344,528
1924	1,698,548	96,625	234,710	94,686	1,272,527
1925	1,757,858	117,333	231,565	92,948	1,316,012
1926	1,733,504	148,771	210,681.	128,743	1,245,309
1927	1,855,722	145,345	201,023	134,185	1,375,169
1928	1,918,427	156,089	177,737	158,243	1,426,358
1929	2,206,648	204,107	197,611	153,624	1,651,306
1930	2,080,324	161,063	184,047	157,862	1,577,352
1931	1,970,007	142,118	143,356	145,502	1,539,031
1932	2,040,316	122,090	112,916	138,646	1,666,664

*Pirtle, T. R. Handbook of Dairy Statistics, U. S. Dept. Agr. 1933.

[1] Includes plain condensed skim, and concentrated skim for animal feeding.

[2] Includes evaporated milk in tins and plain condensed whole milk.

[a] Total of skimmed and unskimmed.

xFigures not available.

description of the several types of equipment in succeeding chapters.

In this country, as well as in Canada, Europe, Australia, and New Zealand, the condensed milk industry grew rapidly. Every succeeding decade marked the organization of new companies and the erection of new factories until today, there are milk condensing factories in nearly every civilized country within the dairy belt. The annual output of condensed milk in the United States and foreign countries is given in Tables 1 and 2, respectively.

Table 2.—Annual Production of Condensed Milk in Different Countries*

Countries	1928 Pounds	1929 Pounds	1930 Pounds	1931 Pounds	1932 Pounds
Australia[1]	53,949,000	51,582,000	45,665,000	41,410,000	
Canada[2]	87,303,627	89,969,405	90,133,170	65,842,623	
Denmark[3]	65,015,000			51,691,000	57,290,000
Great Britain[4]			97,922,000		
Italy[5]					11,023,000
Japan[6]	22,157,000	24,063,000	33,970,000	25,054,000	
Netherlands[7]					255,447,000
New Zealand[8]	17,219,000a	2,175,000	2,305,000	1,004,000	1,813,000
Switzerland[9]	99,207,000	97,443,000	95,900,000	88,184,000	35,274,000
United States[10]	1,918,427,000	2,206,648,000	2,080,324,000	1,970,007,000	2,050,547,000

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*U. S. Dept. Agr., Bureau Agr. Economics.

1. Includes all forms of condensed and dried milk.
2. Total condensed and evaporated whole milk and skimmilk.
3. Total condensed and evaporated whole milk and skimmilk and sterilized cream.
4. Total condensed and evaporated whole milk and skimmilk.
5. Total condensed and sterilized milk.
6. Total condensed and evaporated milk.
7. Total condensed and evaporated whole milk and skimmilk.
8. Total condensed and evaporated whole milk and skimmilk.

8a. Total condensed and evaporated whole milk and skimmilk, and milk powder.

9. Total condensed and evaporated whole milk and skimmilk, and milk powder.
10. Total condensed and evaporated whole milk and skimmilk.

CHAPTER II

THE MILK CONDENSERY

ORGANIZATION, CONSTRUCTION, EQUIPMENT

As in the case of butter manufacture, there are numerous types of organizations that operate milk condenseries, such as the proprietary condensery, the condensery corporation, the stock company with co-operative features and the mutual co-operative condensery. However, the readiness with which these principal classes of organization have lent themselves to the successful manufacture and marketing of the condensed milk differs considerably from the history and experience of creamery organizations.

The Proprietary Condensery.—The proprietary condensery is owned, or operated, or both, by an individual, or by several individuals who have formed a partnership. The owner or owners usually purchase the milk outright at prices based on market quotations for fluid milk prevailing in the territory where the condensery is located. The prices offered are influenced, aside from the market for fluid milk for direct consumption, by the supply and demand for condensed milk, creamery and cheese factory prices and other competitive conditions.

The proprietary condensery patron's responsibility and interest in the enterprise are confined to the sale of their milk to the condensery. The condensery price quotation is known to the patron at the time of the delivery of the milk by him and he does not share in profits nor assume the burden of any losses incurred by the condensery. The profits or losses on the manufacture and sale of the condensed milk are borne by the condensery and, in the case of partnership, are shared according to the amount of money invested by each partner. And, as in all partnership enterprises, each partner is individually liable for all debts of the firm, contracted either with or without his consent.

The proprietary condensery is probably the oldest form of condensery organization and there are still numerous proprietary condenseries in operation. But the natural trend from the start has been toward the organization of condensery corporations and today the great bulk of condensed milk is manufactured and sold by corporate organizations. Most of the proprietary condenseries doing business today do not confine their manufacture to condensed milk alone, but make other dairy products as well. In many cases of these organizations, condensed milk is a side line rather than the dominant product and in such cases manufacture is usually confined to bulk condensed milk either sold to bakeries, confectioners and ice cream factories or utilized in their own manufacture of ice cream and other products.

The Condensery Corporation.—The condensery corporation is a joint stock company without co-operative features. It differs from the proprietary condensery in that it is an incorporated organization. Each stockholder is liable only to the extent of the amount of money he invested. Its relation to the condensery patron is similar to that of the proprietary condensery.

In this age of centralization of production and marketing, the trend toward condensery corporations is very great and it appears inevitable. Within the last decade extensive researches have revealed important scientific facts concerning the causes of condensed milk defects. These causes are of a complex nature and require highly trained men for successful solution. The evolution in the field of condensery equipment has brought about the invention of new, larger, better adapted and more expensive machinery. The increasing competition in the condensed milk markets at home and abroad and the increased cost of raw materials and labor have reduced the margin of profit. All of these factors place the burden of profitable manufacture upon volume production. This in turn makes necessary the operation of larger units, and therefore the investment of larger capital per factory unit, for which the condensery corporation is usually a better adapted organization than any other type of organization. It is for these economic reasons that the trend is strongly away from the small proprietary condensery and the small condensery corporation, and toward the organization and operation of large corporations.

The Joint Stock Company with Co-operative Features.—This type of organization represents a modified combination of some of the features of the condensery corporation with some features of a mutual co-operative association. It embraces some of the advantages and most of the disadvantages of both. To this type of condensery organization also belongs the promoter's condensery.

In this type of organization it is usually intended to have the patrons own the major portion of the stock, in an effort to have a large number of the milk producers financially interested in the condensery and to thereby make more sure of a large and permanent supply of milk. Often, however, much of the stock is sold to and held by townspeople and others who do not keep cows and this fact has, in many cases, proven to be a contributing factor responsible for the failure of the condensery. It has constituted one of the weak links in the fabric of the promoter's condensery, the establishment of which not infrequently resulted in localities which lacked the fundamentals of successful operation—sufficient cows, and farmers embued with the spirit of co-operation so indispensable for this type of organization—because enough stock could be sold to persons other than milk producers, to start the building of the condensery.

There are numerous other reasons, however, why the joint stock company with co-operative features has generally not been successful. In rare cases are such organizations capable of providing sufficient finances to equip an up-to-date condensery for efficient and economical operation. The necessary operating capital usually is lacking. The milk supply territory is too limited to insure volume production. The technical knowledge is not available. The management is inexperienced to cope with the intricacies of the business and the usual board of directors piloting this type of enterprise, consisting of farmers and townspeople of limited experience and judgment, lack the vision and the courage to offer sufficient inducement to attract big men, well qualified to manage the several important branches of the business.

The Mutual Co-operative Condensery.—This is strictly a farmers' co-operative association. Its purpose is to pool the milk of its individual members, the farmers, to manufacture it into condensed milk and to sell the product by the employment of a factory manager.

In a truly co-operative association, every stockholder must be a milk producer, he must be a patron of the condensery, but not every patron need be a stockholder.

For reasons explained under "Joint Stock Companies with Co-operative Features," this type of organization does not lend itself well to the successful operation of a condensery and the mutual co-operative condensery as such has in exceptional cases only been permanently successful. Even in countries where co-operative ownership, operation and control of agricultural enterprises are given preference and have reached an advanced state of successful development the milk condensing branch of the dairy industry is usually vested mostly in proprietary or corporate organization. As striking examples of this fact may be cited Denmark and Switzerland. Both of these dairy countries are recognized as outstanding exponents of successful co-operative enterprise in farming and in dairying. The great majority of creameries in Denmark and practically all the cheese factories in Switzerland are owned and operated under co-operative control. Yet, in both countries the milk condenseries are proprietary or corporate institutions. There are some instances, however, where the combination of numerous co-operative condenseries has succeeded, as is the case in New Zealand, for instance. In such cases the central association usually takes over the sale of the product and frequently also controls the operation of the factories.

LOCATION AND CONSTRUCTION OF MILK CONDENSERIES

Milk Supply.—Other things being equal, the larger the milk supply, the lower the cost of manufacture. A large initial milk supply, with possibilities for extension of the supply territory, is the first essential. The locality in which the condensery is located must be adapted for the production of large quantities of milk; it should be a dairy country where the herds average reasonably large. The advent of the motor truck and the tank car has been a helpful factor in extending the radius and of augmenting the flexibility of the area capable of supplying the condensery with milk within the limits of reasonable cost of transportation.

The establishment and operation of a milk condensery generally acts as an incentive to increased milk production. Yet experience shows that localities which are dairy-inclined and in which the production of milk has already reached a state of large production are more promising than undeveloped territories that require virgin effort to induce the milking of cows. For these reasons the presence of whole milk creameries and cheese factories usually renders a locality attractive for the milk condensery. Here the herds are generally of good size and the farmers are accustomed to take reasonably good care of their milk and to deliver it to the factory daily. Often, though not necessarily always, the condensery prices are sufficiently high in relation to creamery and cheese factory prices to induce the farmers to patronize the condensery.

On the other hand, close proximity to large consuming centers, though dairying may have attained a high state of development, may render a locality of doubtful suitability owing to the continuous and growing demand for market milk. Such competition jeopardizes both volume and economy of the milk supply.

Nor have territories of gathered cream creameries proven particularly promising localities for the establishment of condenseries. While here there generally is no great danger of prohibitive price competition, the farmers usually have small herds and do not look favorably upon the task of delivering the milk daily. They tend to prefer taking or shipping their cream to the creamery once or twice per week. Again, they have learned to appreciate the feeding value of the skim milk and they depend on their skim milk to raise their calves and pigs. When they take their milk to the condensery there is no skimmilk nor buttermilk left for feeding purposes.

Water Supply.—The value to the milk condensing plant of a generous and never-failing supply of clean, cool water cannot be overestimated. The folly of erecting condenseries without first ascertaining the water supply has in some instances compelled milk condensing companies to abandon new plants, because of lack of water.

In addition to the water used in the boilers and for washing purposes, large amounts of water are necessary for condensing and for cooling the condensed milk. It is estimated that the evaporation of one pound of water from fresh milk requires from two to three gallons of water at ordinary temperature, the exact amount of water required varying widely with temperature of available water, temperature at which the milk is condensed, temperature of water leaving the condenser and efficiency of condenser.

The water must be pure. In spite of all precautions, it will come in contact, more or less, with the milk. Though all apparatus and utensils holding and conveying milk and condensed milk may be thoroughly steamed after rinsing with water, there are untold channels through which the milk may become contaminated with polluted water. Thus it may happen that while the milk is condensing, the vacuum pump accidentally stops. If the processor fails to immediately shut off the water supplying the condenser, water will pour back from the condenser into the milk in the vacuum pan. In the case of filthy, polluted water, the entire batch may be ruined. Again, the pan is usually rinsed between batches and, if the water used is unclean, it will contaminate the rinsings as well as the milk of the succeeding batch.

The water should be cold. The colder the water the more satisfactory is the operation of the vacuum pan and the smaller the volume of water required to condense a given volume of milk. Cold water is essential, also, for the prompt and economical cooling of the condensed milk.

Transportation Facilities.—Adequate transportation facilities that provide prompt and efficient service and reasonable freight rates are important. Aside from the incoming fluid milk and the outgoing condensed milk the condensery is dependent on a variety of supplies such as sugar, tinplate, solder, box shooks, barrels, labels, gasoline, coal, etc. The cost of transportation is not only a constant expense but it may at times become the determining factor in the financial success of the business.

Sewage Disposal.—The satisfactory disposal of the factory sewage is an important problem with all dairy products manufacturing plants. The milk condensery is no exception to this fact. The waste of a milk condensing factory is particularly voluminous on account of the large quantity of water that must pass through the condenser of the vacuum pan. The great dilution of this waste, however, renders it less objectionable than the usual creamery sewage.

Where the factory is in a position to connect with the town or city sewer the problem is readily solved. Where this is not possible, a site along a creek, river, pond or lake may offer effective natural means to take care of the condensery sewage. Where no such natural channels of disposal are available it may become necessary to select a site sufficiently elevated to facilitate the flow of the factory waste to a sufficient distance from the factory to insure the plant against foul odors and insanitary conditions. In the absence of all of these avenues for sewage disposal, a properly laid-out system of septic tanks with efficient filter beds may serve the purpose.

BUILDING AND EQUIPMENT

Building Material.—The establishment of a milk condensing factory involves the investment of considerable capital. Such outlay presupposes faith on the part of investor in the permanency of the business. For a permanent business, substantial construction promises maximum economy. In addition to the factors of economy and durability of construction, consideration should be given to the sanitary phase of building, materials and construction.

It is beyond the realm of this volume to provide detailed plans and specifications for the construction of condensed milk factories. Such details must of necessity vary with locality, availability of materials, capacity of contemplated plant, type of equipment, financial resources and personal preferences of individual owners. They are usually best decided on and worked out to suit the specific occasion for each individual factory separately and when needed. There are a few fundamentals, however, which apply to all factories in which milk or milk products are handled or manufactured and which may be briefly enumerated here.

Floors.—All floors of the manufacturing rooms should be of impervious material, preferably of properly laid cement finished with a hardener, such as Master Builders' Cement, Lapidolith or similar material that will insure the needed wear-, water-, dust- and crack-proof properties of the surface. High grade, well-laid tile may also be considered suitable for surfacing. In case of wooden walls or inside walls and partitions a cove of impervious material such as concrete, brick or plaster should be extended several feet above the floor.

All floors of the manufacturing rooms should slope evenly and sufficiently to provide rapid and complete drainage into an ample number of well-placed large, water-sealed floor drains. The top of these floor drains should be at least one-eighth inch below the surface of the adjoining floor. In large rooms open drain-ditches in the floor, of proper width, depth and slope, and covered with perforated iron plates, or iron grating, may prove preferable to bell traps. It is generally advisable to lay the floor ditches not more than forty feet apart to insure satisfactory drainage without an inconveniently steep slope of the floor. The main sewer pipe carrying off the factory drainage should be not less than ten inches in diameter for a condensery receiving about fifty thousand pounds of milk daily. An easily accessible "clean-out" should be provided in the sewerage line outside of the factory walls.

Ventilation.—An efficient system of ventilation is an important though too often neglected factor in the planning of the condensed milk factory. This is especially essential in parts of the factory where there is much escape of free steam and where the rooms are too large to enable the windows in the side walls to serve the purpose.

The ventilating system should be adequate to afford ready and quick escape of steam, to remove foul air and to facilitate the proper control of temperature. Unless free steam finds an exit from the factory rooms promptly, it condenses on walls and ceilings, causing profuse sweating which deteriorates walls and ceilings, damages motors and belts, corrodes metal surfaces, and encourages the appearance of mold on building, equipment and supplies. Such condensation and its damaging effect may become especially serious during cold weather. The removal of foul air and the temperature control are essential for the comfort, health and efficiency of the employes.

General Plan of Factory and Arrangement of Equipment.—It is not the purpose of this volume to discuss in detail factory plans and arrangement of equipment. Such discussion would at best fail to serve those contemplating the establishment of a condensery. The most suitable arrangement for each factory must be determined on the basis of local conditions, capital available, topography of land, number and kind of products to be manufactured, volume of business expected, type of machinery used, extent to which labor-saving devices are to be used in the place of man power, and many other factors. It may suffice here to merely call attention to the general trend of present day preference for factory layout.

In the early days when most of the milk arrived by individual deliveries, when the weighing equipment was confined to a single weigh can mounted on ordinary platform scales, when the cans had to be lifted high for "dumping" and were washed by hand, the receiving of milk and the cleaning of the empty cans was laborious and slow, requiring much personnel and delaying the beginning of the condensing operation. The milk had to be held for a considerable length of time before it reached the vacuum pan and much space and equipment was needed to hold and keep cool the slowly accumulating milk.

The cooling of the condensed milk was done in ten gallon cans, the handling of which required much room, labor and time. The filling, sealing, and packing of the tins was done by hand, calling for a large force of factory help, large space, and making progress slow. The factory force was so large that it was considered desirable to divide it into separate rooms or departments necessitating a foreman for each room.

The evolution in equipment and processes of manufacture and of handling the finished products have been the means of reducing the necessary floor space and increasing the capacity of the factory, of doing away with obstructing partitions, of eliminating much laborious work, of simplifying factory operation and of greatly speeding up the entire process from weigh can to the car on track loaded with the finished goods ready for the market.

The automobile truck, the tank truck, and the tank car now bring the milk to the factory in larger units and faster; labor-saving improvements in the equipment and method of "dumping" and weighing the milk and the use of the mechanical can-washer have increased the capacity of the milk receiving floor, ridding it from the accumulation of large stacks of empties, facilitating the return of the empties, keeping the farmers' wagons and trucks on the constant "move," and reducing labor and personnel on the receiving platform.

Mass cooling or the use of the continuous cooler for the condensed milk reduces the space, equipment and man-power at this point of operation; the use of automatic filling and sealing machines makes obsolete the operation of separate departments and rooms lined with long benches manned by scores of girls and supervised by a department foreman for this work; the advent of the continuous sterilizer and automatic can-tester does away with the heavy work of lifting, stacking, inspecting and restacking of the heavy trays of filled tins, it eliminates the numerous units of batch sterilizers and the use of incubating rooms; the operation of suitable case conveyors reduces the labor and time for the loading of the cars, etc.

These and similar other improvements in equipment and method of operation are responsible in a large measure for the rapid change from the two or more story condensery with partitioned-off departments or rooms for each major operation, to the one story, one room condensery for all manufacturing and packing operations. The power equipment, for obvious reasons, is confined to a separate room. In most cases the milk receiving platform is also partitioned off and is usually and preferably installed on a level sufficiently elevated above the manufacturing room to permit the milk to flow to the tanks and heaters by gravity. The testing room or factory laboratory is also housed in a room by itself and most condenseries have one or more refrigerating rooms.

But outside of these special departments, the very nature and purpose of which renders their operation more or less independent of the factory work proper, the tendency in factory construction and arrangement of equipment today is for one-story factories and to do away with all partitions, doing all the manufacturing in one large room. In this case it is customary and usually most convenient and serviceable for easy and economical operation to place the vacuum pan and possibly the condensed milk storage tanks on an elevated platform and to install the hotwells, coolers, vacuum pumps, milk pumps, homogenizer, filling and sealing machines, sterilizers, labeling and packing machines on the main floor which also provides the necessary space for the stock of supplies and of canned goods. Where the condensery manufactures its own tin cans, this work is usually done in a separate building, suitably located for receiving its supplies from track and for conveying the empty tins into the factory at the place where needed.

List of Equipment.—The equipment must of necessity vary with the kind of product it is intended to manufacture. Instead of assembling a general list of equipment at this point, which would be of little direct value, the equipment needed for sweetened condensed milk and evaporated milk is diagrammatically illustrated, listed and described in Chapters IV and XII, respectively. For a complete list of all equipment and accessories and cost thereof, best suited to the requirements of any given set of conditions, the reader is referred to firms manufacturing milk condensing machinery and making a business of equipping entire plants. A list of such firms is appended to this volume under "Index to Advertisers."

Economic Arrangement of Machinery.—In the arrangement and connection of the machinery, economy of manufacture and sanitation of the product should receive serious consideration. The machinery is best so arranged as to reduce to the minimum the space, pumps, pipes and conveyors needed. Pumps, conveyors, pipes and fittings are expensive. In addition to their initial cost of installation there is the labor cost of daily handling and care, the extra floor space needed and the expense of upkeep. The space saved by judicious arrangement of the stationary machinery may be used to advantage for other purposes.

Human muscle is the most expensive form of motive power. Wherever muscle can be replaced by machinery and where, by intelligent arrangement of the machinery, unnecessary steps and handling can be avoided, the cost of manufacture is reduced.

Tight joints in all water, steam, brine and ammonia lines, suitable and adequate insulation of all water and steam pipes, and of all brine and ammonia lines between brine tanks, coolers, and compressors, and economical use of exhaust steam and hot condensation water from radiators, steam engines, steam pumps, coils and jackets of vacuum pans and heaters, are important factors in keeping the waste and cost of fuel, power and water down to the minimum and in accomplishing factory efficiency.

Sanitary Construction and Arrangement of Equipment.—Milk pumps, milk pipes, milk troughs and all other milk conveyors are, at best, enemies of sanitation. There is wisdom in their avoidance wherever possible. Where economy of installation and operation permit, the gravity system of conveying deserves preference over the use of pumps. The surfaces coming in contact with the milk or milk products in vats, kettles, tanks, etc., should be smooth, with flushed seams and properly finished welds. All surfaces to which the milk is exposed, and the condenser of the vacuum pan should be readily accessible for cleaning. Long milk pipes should be equipped with unions at reasonable intervals and with steam connections. Removable elbows or crosses assist in cleaning without the necessity of daily dissembling of pipe lines. In the selection of equipment consideration of the choice of metals is important, both from the standpoint of resistance to corrosion and of their effect on the quality of the milk as explained in succeeding paragraphs.

METALS IN DAIRY EQUIPMENT

Effect of Metals on Milk.—It has been known for some time that prolonged contact between certain metals and milk may and usually does have a damaging effect on the milk product, jeopardizing its flavor and keeping quality. More recent study of the reactions involved has definitely shown that the great majority of metals, metallic alloys and plated metals used in dairy equipment are more or less soluble in such milk acids as lactic, butyric, citric and acetic, and there is evidence that some of the mineral salts and even the colloids of milk are capable of inducing metallic corrosion. This action of milk on metals is not infrequently intensified by electrolysis, such as may result from the presence of metals with different electrical potentials in contact with each other in one and the same piece of equipment, the fluid milk product acting as the electrolyte, or from stray electric currents in the factory.

The metallic salts and oxides formed as the result of reactions between milk and metals are capable of affecting the milk product in several ways. Most of the metallic salts themselves have a pronounced astringent, puckery, bitter, metallic taste and their mere presence in the milk conveys this same character to the flavor of the dairy product. This is especially the case with the salts of copper and zinc and to a lesser extent of iron, while the salts of tin, nickel and aluminum lack this intensity of metallic taste. The salts of some metals are active as oxidizers and catalyzers and their presence tends to induce complex chemical changes in the milk product, usually involving the milk fat. These changes are of a progressive nature, jeopardizing the keeping quality of the manufactured product. Copper salts are particularly active in this respect. Iron and zinc salts also have these properties, but to a somewhat lesser extent.

The damaging reaction of metallic salts may involve also selective influences on bacteria causing acceleration of the development of certain objectionable forms of germ life, destruction of vitamins, and the development of toxic properties. The nature and extent of these objectionable influences of the metallic salts in dairy products, however, is not as yet fully understood and further extensive investigation is needed for dependable conclusive evidence.

Suitableness of Metals for Milk Work.—The metals, metallic alloys, metal coatings and metal veneers, structurally, physically and economically suitable, that are available for the construction of the "milk side" of dairy equipment are principally the following:

Single Metals: iron, copper, nickel, aluminum.

Plated Surfaces: tin, zinc, chromium, aluminum.

Metallic Alloys: Copper alloys, such as nickel silver, white metal, etc.; chromium-nickel-steel alloys, such as Allegheny Metal, Enduro KA2, etc.; Chromium-nickel alloys, such as Inco Chrome Nickel; Aluminum alloys.

Metallic Veneers: Chrome-nickel-steel on iron, such as IngA-clad and Plykrome clad; chrome-nickel on iron, such as Inconel clad steel; nickel on iron, such as nickel clad steel; pure aluminum on aluminum alloy, such as Alclad; glass enameled steel; rubber-lined steel.

Single Metals.—From the discussion in previous paragraphs it is evident that metallic surfaces of bare iron and copper are damaging to milk and milk products. Both metals are attacked by and are soluble in milk. Copper salts, such as copper lactate, have an intense puckery, metallic, bitter taste and are active oxidizers and catalyzers. Iron salts have similar properties but to a somewhat lesser extent. Nickel and aluminum are also slightly soluble in milk. Their salts, however, lack the intensive metallic taste and their oxidative and catalytic tendencies in milk products have been found sufficiently negative to render their presence harmless. They do not jeopardize the chemical stability of the dairy product.

While the effect of nickel on the milk is negligible, the corrosive effect of the milk on the nickel may become very severe under certain combinations of conditions of operation, such as for instance, in the case of the regenerative cooler where the inclosed heated milk with its confined content of dissolved air is capable of eating away entire sections of the upper tubes. The chief weaknesses of aluminum equipment lie in the pitting effect by hot milk of aluminum that contains impurities, and the lack of resistance of aluminum to alkalies, such as are used in washing solutions. The latter drawback is readily overcome, however, by admixture of corrosion preventives, such as sodium silicate.

Plated Surfaces.—Tin, while slightly soluble in milk, yields salts with a relatively mild metallic taste and that are sufficiently inert to exert no damaging chemical action on the dairy product. It is for this reason that properly tinned metal surfaces have become universally recognized as highly suitable for use in practically every type of milk equipment and the relative cheapness of tinned iron and tinned copper has further enhanced the popularity of tinned metal surfaces. The permanency of the tin coating, however, leaves much to be desired, especially in the case of heating surfaces that become coated with casein or milk stone and for the removal of which strong alkalies or abrasive agents must be used. Experience has shown that the tin coating on heating surfaces is of such short duration that their tinning is of no practical value and the frequency of the necessity of retinning is too expensive to justify the tin coating.

Chromium plating of the milk side of equipment, while highly satisfactory as long as the coating remains intact, has not as yet reached sufficient perfection to justify its adoption in milk equipment. Nickel plating, likewise, provides satisfactory protection of the base metal and of the milk product against damaging metallic action. The chief drawback here too, however, lies in the peeling-off tendency of the nickel coating.

Zinc plating or galvanizing is not suitable for milk equipment. While the zinc coating protects the milk against the damaging action of iron, the zinc itself is acted upon by the milk.

Galvanizing protects the iron in two ways,—namely by a surface coating of zinc and by the fact that the zinc coating is electropositive to iron, which means that in the case of electrolytic action in the presence of milk, the iron remains protected while the zinc suffers corrosion. While iron salts are thus kept out of the milk, this advantage is offset by the fact that the zinc salts so formed are equally objectionable, as they themselves have a very astringent metallic taste and are capable of reacting with the milk chemically.

Metallic Alloys.—Alloys containing a considerable proportion of copper are not suitable for milk work. This refers to a great variety of metallic alloys of which nickel silver and white metal are perhaps the best known. The higher the copper content the greater the risk of damage to the milk product. On account of wide differences in copper content and composition between the individual copper alloys available, their respective corrosiveness and injury to milk has been found to vary. The direction and kind of effect of most copper alloys is similar. It is not unlike the effect of copper itself and experimental study has, in fact, revealed that the copper they contain is capable of going in solution in the presence of milk. The intensity of effect on the other hand, varies with the proportion of copper they contain. The safest alloy containing some copper appears to be Monel Metal. Its copper content is relatively low. While it is not entirely free from the objection raised in connection with copper and copper alloys, it has proven highly suitable for some phases in the handling of dairy products. This is particularly the case with monel metal equipment in which the dairy product is handled cold.

Aluminum alloys which usually contain manganese to improve upon the physical hardness of the aluminum, have proven equally satisfactory in milk work as pure aluminum but, like aluminum, they are sensitive to the corrosive action of alkalies.

Chrome-nickel steel alloys, such as Allegheny Metal and Enduro KA2, are insoluble in milk and have proven eminently satisfactory in milk work. They are not corroded by milk, hot or cold, and sweet or sour, and they have no action on the milk. These alloys have been used in diverse milk equipment for a number of years and have demonstrated their superiority in milk work. Their extreme hardness presented difficulties in fabrication when they were first introduced. These difficulties have been largely mastered now and are no longer a serious problem. The high cost of chrome-nickel steel, however, is still an obstacle to its more general use in milk equipment.

A chrome-nickel alloy, sold under the trade name "Inconel," which has recently been brought to the attention of the dairy industry and of the fabricator of dairy equipment, appears to combine the superior corrosion resistance to milk of chrome-nickel steels, with greater ease of grinding and polishing because of its diminished hardness. It requires no subsequent heat treatment to restore corrosion resistance after welding and its lower co-efficient of expansion reduces buckling. Experimental results have shown this new alloy to be highly suitable for milk work under a variety of conditions, and meriting its favorable consideration in the construction of every type of milk equipment. Its cost is as yet comparatively high, which may have a tendency to retard its general adoption somewhat. See also "Results of Additional Experiments" later in this chapter.

Metallic Veneers.—Efforts to reduce the cost of the corrosion-resistant and highly satisfactory chrome-nickel steel, chrome nickel and nickel surfaces in dairy equipment have resulted in the development and perfection of the art of lining ordinary steel with a thin sheet of corrosion-resistant alloy or metal. These efforts have brought forth several new products known by their respective trade names as IngA-Clad, Plykrome, Inconel clad and nickel clad.

When used in the construction of dairy equipment the non-corrosive veneer is on the milk side, thus providing similar protection of the milk against metallic corrosion and damage to flavor as would be the case with solid walls of chrome-nickel steel, chrome-nickel, and nickel, respectively, but at considerably lower material cost. In the case of IngA-clad, for instance, made with Allegheny metal clad, the chrome-nickel steel cladding is 20% of the total thickness, and the balance of 80% is made up of mild steel backing.

A similar type of product is available also in the form of a pure aluminum covering or veneer over an aluminum alloy. For example, the heat-treated aluminum alloy 17-S is offered, covered with pure aluminum and is known as Alclad. The pure aluminum is applied to the aluminum alloy somewhat similarly as the covering of stainless steel to the mild steel in the production of stainless steel clad steel.

Glass Enamel Steel has been successfully used in the construction of dairy equipment for several decades. The glass enamel has proven a complete protection to milk against damage from metallic salts. It is not acted upon by the milk and it has no damaging effect on the flavor and keeping quality of the milk product. While the enamel coating is not indestructible, its durability under normal conditions of use is sufficient to preserve it in satisfactory condition over a considerable period of service. The low heat conductivity of both the glass enamel and its heavy background of steel, and the corrosive character of the steel side, renders glass enameled steel unsuitable as a heating and cooling surface. The proper place for glass enameled steel lies in its use for linings of coil vats and for shells of milk storage tanks. For these purposes it has amply proven its great usefulness and satisfactory service.

Rubber-Lined Steel.—Experiments with rubber-lined milk tanks and vacuum pans indicate the feasibility of lining the milk side of metal surfaces with a compound of hard rubber. The rubber lining appears to completely protect the metal from corrosion and to have itself no harmful effect on the flavor of the milk. Such equipment obviously has the added advantage of low material cost and low cost of fabrication. There is need, however, of more extensive trials to determine the suitability of such equipment for milk work, particularly with reference to its behavior under intensive heat treatment.

Choice of Metals for Condensery and Milk Powder Equipment. Vacuum Pan and Hot Wells.—The vacuum pan and hot wells or forewarmers are the most important parts of the condensery equipment as far as consideration of metallic effect on the finished product is concerned. It is in this equipment that the fluid milk is heated and agitated for a considerable period. This treatment brings the milk in its most active state in intimate contact with metal surfaces in the presence of heat.

From the very inception of the condensed milk industry this all-important equipment has been constructed of copper, and the copper vacuum pan and copper hot well still are very much in evidence in the factories of concentrated milk products. In this equipment the metal surfaces that are in contact with the milk are bare copper. The tinning of the copper surfaces has been found useless because of the short life of the tin coating on metal surfaces that require daily scouring with abrasives, such as is the case with forewarmers and vacuum pans in which the milk receives intensive heat treatment, causing deposits of milk proteins and milk stone.

It is well known that such defects as metallic flavor and tallowiness in condensed milk and fishy flavor and tallowiness in dried whole milk are either incited or intensified by the presence of copper salts, probably through oxidative and catalytic action of these metallic salts on the milk fat. Excessive contamination of the concentrated or dehydrated product with copper salts impairs flavor and keeping quality and jeopardizes the market value of the finished product.

Condenseries that have changed from copper vacuum pans to chrome-nickel steel vacuum pans have observed a marked improvement in the flavor of their product. Grindrod, using the vacuum pan for treating milk and milk products with his process of "Impact Sterilization" (steam under pressure is injected into milk under vacuum through a multitude of fine jets) reports that the product from vacuum pans constructed of all nickel and of all chrome-nickel steel, respectively, was superior in quality to that treated in the copper vacuum pan.

Condition of Copper Surfaces.—The amount of copper that will dissolve and the extent to which copper salts enter the manufactured product is influenced very greatly by the condition of the copper surfaces. In the presence of brightly polished surfaces the solution of copper in milk and the damage done to quality are relatively small. Unclean and tarnished copper surfaces, on the other hand, yield relatively large quantities of copper salts and constitute a constant menace to the quality of the milk product. Conditions especially conducive to damaging contamination of the milk product with copper salts and oxides are idleness of hot wells and pans long enough to invite tarnishing, and the re-use of such equipment without previous thorough scouring; incomplete removal of all remnants of milk after use; and particularly, neglect of thorough daily scouring of the upper parts of the vacuum pan—the dome and goose neck. Contact of the copper surfaces with atmospheric air during the interim between operating days, invites tarnishing, corrosion and the formation of soluble copper compounds which are washed into the milk of succeeding batches. The tarnishing and corrosive effect of the air is intensified in the presence of remnants of milk.

The fact that the condensed milk defects resulting from copper contamination have been largely confined to temporary and local outbreaks, and that the manufacturer has, as a whole, escaped costly prolonged sieges of milk deterioration from this source, is attributable to the general high sanitary standard of condensery equipment and to the fact that the treatment of the milk in the open hot wells and in the vacuum pan operates in the direction of liberating the gases dissolved in the milk, and that the usual forewarming temperatures employed are above the temperature of maximum of copper corrosion in milk.

Dissolved Gases in Milk.—Dissolved gases in the milk and temperatures up to 70° C. (158° F.) greatly intensify corrosion and solution of copper. The usual temperature to which the milk is forewarmed in the hot wells is well above this heat (170° F. or above). The temperature of vacuum pan operation (approximately 130 to 145° F.) is more conducive to action of the milk on the copper, but the violent boiling of the milk under reduced pressure is highly effective in freeing the milk from dissolved gases, thus minimizing copper corrosion. Copper immersed in heated milk under vacuum suffers far less corrosion than when similarly immersed under atmospheric pressure.

Copper Vacuum Pan and Hot Wells a Menace to Quality.—On the basis of the above observations it is obvious that the copper hot well and the copper vacuum pan constitute a fundamentally potent source of damaging copper contamination of the milk. The substitution of copper with metals or alloys of proven resistance to corrosion and of demonstrated harmlessness to the milk product, such as chrome-nickel steel and chrome-nickel alloys offers the most dependable protection of the milk against damaging metallic contamination. The jeopardy of copper equipment to the quality of the concentrated product is minimized somewhat by the high forewarming temperatures employed and by the expulsion in the vacuum pan of the oxidation-promoting gases dissolved in the milk. Attention to scrupulous cleanliness by daily scouring after use, that renders and keeps the copper surfaces bright and shining and by thorough rinsing with hot water before each day's use, are indispensable precautions that assist in reducing milk defects due to the use of the copper forewarmer and copper vacuum pan to the minimum.

Preheaters and Continuous-Flow Forewarmers.—In the case of continuous-flow forewarmers and also preheaters for hot well forewarming, the continuous supply of dissolved air contained in the inflowing fresh milk materially intensifies the corrosive action. In these continuous flow heaters, however, there is a greater tendency for the metal surfaces to become coated with a protecting milk film, thus diminishing metallic contamination, except in the case of copper and high copper alloys on the surfaces of which film protection appears negligible.

Preheaters and continuous forewarmers exposing the milk to surfaces of bare copper or copper alloys, may be expected to contaminate the milk liberally with copper salts. The most suitable metal for this type of equipment appears to be chrome-nickel steel or chrome-nickel alloy. Pure nickel has also proven a safe and serviceable metal for this type of equipment, because of the facility with which pure nickel acquires protective coatings in milk heaters, and the positive protection afforded by such coatings. Tinned copper surfaces fail to provide dependable protection because of the short life of the tin coating on the heating surface.

The Drop Tank.—The drop tank, likewise, receives the milk while hot. At this stage the concentrated milk should be relatively free from dissolved air, but the temperature is favorable for metallic action and damage from surfaces of copper and copper alloys. Chrome-nickel steel and chrome-nickel suggest themselves as most suitable, but tinned copper is also quite serviceable here, since no heating surfaces are involved and the danger of milk deposits on the metal surface, the removal of which would require treatment damaging to the permanency of the tin coating, is remote. Glass enamel surfaces are likewise suitable for this purpose.

Condensed and Evaporated Milk Coolers.—For the cooling of sweetened condensed milk and evaporated milk tinned copper surfaces are entirely satisfactory and, because of their superior heat conductivity and relatively low cost, are perhaps the most economical. Iron milk tubes in the sweetened condensed milk continuous-flow cooler are objectionable, both because of the corrosiveness of the iron and for sanitary reasons.

Holding and Storage Tanks.—For fluid milk holding tanks and condensed milk storage tanks, tinned copper, glass enameled steel and aluminum have been found highly serviceable.

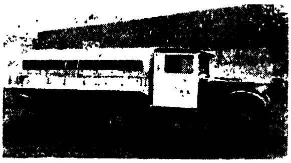


Fig. 7. IngA-clad milk tank truck

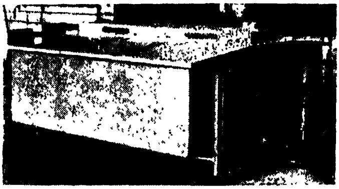


Fig. 8. IngA-clad milk storage tank

Courtesy of Ingersoll Steel and Disc Co.

The clad materials, such as IngA-clad, Inconel clad, Plykrome, nickel clad and Alclad are also well suited for this purpose. All-nickel and all-stainless steel, while highly satisfactory, are usually avoided because of high initial cost of such large equipment constructed of these more expensive metals.

Milk Pipes and Fittings.—For milk pipes and fittings tinned copper sanitary tubing is preferable to nickel-silver tubing. Prolonged use of the latter tends to build up in its interior a coating of copper compounds that are soluble in the hot milk. While the tin coating in the tinned copper sanitary tubing is not particularly permanent, yet experience has shown that tinned copper tubing, kept in proper sanitary condition, rarely jeopardizes the quality of the concentrated product. Stainless steel tubing, where used, has given highly satisfactory service and would, over a prolonged period of use, undoubtedly prove economical, notwithstanding its relatively high initial cost.

Black iron pipes are not suitable for condensery milk pipes unless sandblasted on the inside. Their rough inside surface renders thorough cleaning difficult, they readily become foul and their tendency to contaminate the milk with rust and scale is ever-present. Galvanized iron pipes and fittings are objectionable for reasons explained previously under "Plated Metals."

Drum Dryers.—For both vacuum and atmospheric drum-dryers, the cast iron drum is used almost exclusively. High grade milk drying drums are manufactured of a special grade of cast iron that has a particularly close grain, possesses high tensile strength and gives fairly high and uniform heat transfer. Sheet metal has also been tried but, while advantageous from the standpoint of increased heat transfer, has been found objectionable on account of the tendency of deflecting and bulging of the thinner drum wall and of more profuse rusting. Experimental data, showing to what extent, if any, the cast iron drum surface jeopardizes the quality of the resulting milk powder, are lacking.

The use of corrosion resistant alloys, such as stainless steel, etc., for drum construction, is considered out of question on account of prohibitive cost. The plating of the drums with metals that are known to have no damaging effect on the milk product has not been found satisfactory. Tin plating is of short life because of mechanical wear by the metal scraper. Nickel plating, even when highly polished, causes objectionable sticking and difficult removal of the film of dried milk. Chromium plating, while undoubtedly more durable when properly done, would increase the cost of a dryer nearly 50%.

Recently a nickel-cast iron alloy[272] known by the trade name "Ni-Resist," has been introduced in the construction of drum dryers used for milk. This alloy contains 20 per cent nickel and no copper. While still in the experimental stage, its initial performance promises distinct advantages over all-cast iron drums.

Spray Drying Chambers.—In the usual construction of the spray drying chambers, the chamber is lined with tin plate, generally asbestos-insulated on the outside. This construction is inexpensive and it appears to serve the purpose well. The walls of the drying chamber do not come in contact with liquid milk.

They usually become loosely covered with dry milk flakes which have no noticeable corrosive effect. Nor is there need of the use of strong alkalies or abrasives for cleaning. Corrosion and wear on the tin coating therefore are negligible and the tin surface offers dependable protection against damaging metallic action on the dried milk. Some of the drying chambers are constructed of galvanized iron which is undoubtedly the least desirable metal as far as its possible effect on the quality of the powdered milk is concerned, particularly in the case of whole milk powder and cream powder. Other materials of construction consist of ·tinned copper, and glazed tile. In some of the newer installations stainless steel is being used which obviously is highly suitable for this purpose.

Results of Additional Experiments.—The above brief discussion of metals in dairy equipment summarizes the experimental results and commercial experiences of the author[4, 5, 6, 7, 8, 9] and the findings of numerous other investigators on the subject.[10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28] Since this manuscript was prepared an important treatise on "Metals and Condensed Milk" by Thompson, Mears, Searles and La Que[160] has appeared dealing with a specific experimental study of corrosion of metals contained in condensed milk equipment under commercial operation. These results appear to corroborate previous findings and observations and add much valuable new information. The metals studied were of the following composition:

Copper—99.9% pure.
Nickel—99.5% pure.
Tin—99.9% pure.
Bronze—87% copper, 5% tin, 3% zinc, 5% lead.
Inconel—80% nickel, 6% iron, 13% chromium.
Monel—29% copper, 68% nickel, 1.5% iron.
Soft Solder—33% tin, 67% lead.
Silver Solder—25% copper, 15% zinc, 60% silver.
Chrome-Steel—83% iron, 17% chromium.
Chrome-Nickel Steel—8% nickel, 74% iron, 18% chromium.

The authors of the above experiment report the following conclusions:

"1. Corrosion was most active in the evaporators, hot wells, drop tanks, and preheaters, and probably also in the coolers for condensed and evaporated milk.

"2. In every test the corrosion resistance of copper was surpassed by some of the other metals that have good physical and fabricating properties. The advantage of the other metals was greatest at the points where corrosion was most active. All the other metals showed an advantage over copper in the evaporators.

"3. The metal pick-up from typical evaporators was estimated as 2.5 p.p.m. for sweetened condensed milk and 1.6 p.p.m. for evaporated milk.

"4. A hard film was found on the specimens during long-time tests in evaporators. A similar film was formed in the fluid milk preheater during six hours. The film exerted a protective influence which was least on copper."

Careful study of the tabulated results of the above experiment further reveals the outstanding resistance to corrosion of chrome-steel and low-iron chrome-nickel steel as well as 18-8 chrome-nickel steel and tin. Corrosion of these alloys and metals was in all cases negligible or entirely absent. The results further show that in the case of the copper vacuum pan corrosion is most intense in the upper portions of the pan, the dome and goose neck, emphasizing the importance of daily scouring of these parts which are least accessible and are, therefore, often neglected in the daily routine of cleaning.

CHAPTER III

MILK SUPPLY

Basis of Buying Milk.—In general, the price paid by the condensery in regions and milk sheds of large consuming centers is subject to the price of fresh milk distributed in those regions, and in regions where creameries and cheese factories predominate condensery prices are largely influenced by butter and cheese prices. Thus it was shown by Nardin[23] that the price in Illinois is subject to prices of fresh milk distributed in Chicago and St. Louis. Prices in New York State and Pennsylvania have been subject to influences of the New York Dairymen's League and the price of fresh milk for distribution in the city of New York. The Wisconsin price is pre-eminently affected by butter and cheese prices.

In normal times condensery prices average approximately 25 to 50 cents per hundred weight of milk higher than those paid by creameries and cheese factories. During the four-year period of the World War, the range of this differential was much wider. There were times when condensery prices exceeded creamery and cheese factory prices by over one dollar, while at other times condensery prices even dropped below those paid by creameries and cheese factories.

The spread between condensery prices and creamery and cheese factory prices varies with the market demand for condensed milk, the available supply of fluid milk and the feeding value of skimmilk as based on the market price of corn. Generally speaking, when the volume of milk supply of the condensery approaches or exceeds the market demand for condensed milk, condensery prices sag and may drop to near and even below the price paid by creameries and cheese factories. Thus it has been customary for the condenseries to pay the highest differential over and above creamery and cheese factory prices in winter, during the time of low supply, and to drop condensery prices very close to those paid by creameries and cheese factories in summer, during the flush of the milk producing season.

However, the fact that in case of a surplus milk supply to condenseries and fresh milk distributing plants, these milk sheds drain their surplus into the creameries, often changes the picture of differential between condensery and creamery. This absorption of the surplus condensery milk by the creamery increases butter production and depresses the butter market. Particularly during periods of sustained surplus of condensery milk, therefore, creamery prices may suffer as great a drop as condensery milk prices, and the spread between the two fails to diminish.

Formerly the condenseries paid for the farmers' milk on the basis of gallons and by the hundred weight regardless of fat content. This encouraged the development of the breeds of low-testing milk in condensery territory and it led to the erroneous impression that Holstein, Ayrshire and Brown Swiss milk was better suited for condensery purposes than milk of the Channel Island breeds.

Today the great majority of American condenseries are buying their milk either on the straight butterfat basis, or on the basis of an established basic price per hundred weight of milk of a specified standard fat content, plus a bonus for richer milk and a penalty for milk below standard. Assuming, for instance, that the standard price applies to milk testing 3.5 per cent fat, an added bonus of say four cents is paid for each one-tenth per cent above 3.5 per cent, and a deduction of four cents is made for each one-tenth per cent below 3.5 per cent.

In countries where one breed overwhelmingly predominates, or where the predominating breeds all yield milk of similar richness and where the freshening of the majority of cows is fairly evenly distributed over the twelve months of the year, the milk generally continues to be bought on the basis of its weight or volume, and not by test. Under these conditions the objection of not paying on the butterfat basis is, in part at least, removed.

The great bulk of the milk supply reaches the condensery by wagon or by motor truck. Usually part of the cost of transportation is borne by the factory and part by the farmer. Some milk condensing concerns operate concentration points to which the milk is hauled by the patrons, and from which it is hauled to the factory in large tanks mounted on motor trucks. Some milk also arrives by rail, either in individual farmers' cans or in tank cars. Payments for the milk are generally made monthly.

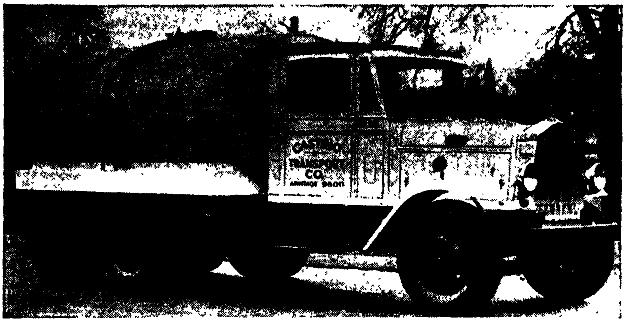


Fig. 9. Glass-lined milk tank truck
Courtesy of The Pfaudler Company

Some condenseries operate concentration points where the milk is received, cooled and shipped to the central factory. In some instances the milk is also pre-condensed in these receiving plants and shipped to the central plant in concentrated form.

Quality of Fresh Milk.—The quality of the fresh milk is a most important factor in the successful manufacture of marketable condensed milk. The milk condensing factory ignoring this fact is bound to pay the penalty in the form of difficulties in manufacture and losses due to spoiled goods sooner or later.

The fitness of milk for condensing purposes is determined largely by those factors in the condition and care of the milk on the farm that influence its heat coagulation point. These factors have to do with the health, period of lactation and feed of the cows, and the care of the milk after it is drawn. The first group of conditions are important in so far as they influence the original composition and character of the milk. To the second group belong those factors that determine the presence or absence of changes due to fermentation.

Effect of Health, Period of Lactation and Feed of Cows on Fitness of Milk for Condensing Purposes.—Cows that are in feverish or otherwise abnormal condition, or that suffer from disease, or have diseased udders, generally yield milk of abnormal character. The physiological functions of such cows are usually impaired or abnormal and the product of milk secretion, the milk, is often abnormal in composition and reaction. In such cases it appears to be especially the balance of mineral salts and the amount or character of proteins that are affected. These changes affect the stability of the milk proteins and generally lower the heat coagulation point.

The period of lactation is a factor in so far as milk within a short time before the end of the milking period (less than 30 days) or milk immediately after calving (about the first 14 milkings), is abnormally high in albumin and may contain abnormally large quantities of other unstable proteins such as lactoglobulin, etc. Milk of such abnormal condition has a low heat coagulation point, as shown in Chapters XV and XXIII.

The effect of feed on the fitness of milk for condensing purposes is not so well understood. It is believed that green feeds, such as blue grass pasture, tend to improve the salt balance, increasing the citric acid content. Fermented and decayed feeds, on the other hand, jeopardize the quality of the milk and its stability toward heat through their unfavorable effect on the health and physiological functions of the cows and possibly by increasing the acidity of the milk. Such feeds obviously also tend to interfere with the flavor that is characteristic of good milk.

Milk rendered abnormal, because of the above or other similar conditions, jeopardizes the quality of both sweetened and unsweetened condensed milk. In the case of sweetened condensed milk there is danger of the appearance of lumps in and of abnormal thickening of the finished product. In the case of evaporated milk the tendency lies in the direction of sterilizing difficulties, because of the abnormal sensitiveness of such milk toward heat, causing excessive curdling during sterilization.

Effect of Care of Milk on the Farm on Its Fitness for Condensing Purposes.—Any condition that causes or accelerates fermentation changes in milk usually tends to lower its heat coagulation point, thereby rendering it more sensitive toward heat. Milk produced and handled under insanitary, unclean conditions, is subject to excessive bacterial contamination. These bacteria may give rise to increase in acidity or they may produce rennin-like substances. These products of fermentation tend to lower the heat coagulation point, causing abnormal curdling and may give rise to thickening of the product after manufacture.

The harmful effect of such contamination is intensified by absence of prompt and proper cooling of the milk as soon as drawn and keeping cool until delivered to factory. Delivering the milk to the factory less often than daily further encourages fermentation and depreciates the suitableness of such milk for condensing purposes.

Heat Treatment During Manufacture Fails to Protect Finished Product from Consequences of Contamination of Raw Milk.—The assumption that the contamination of milk with germ life is made harmless by the heat employed in manufacture is not altogether correct. While it is true that the usual forewarming temperatures employed (about 200° F.) are capable of destroying most of the vegetative cells of bacteria, yeasts and molds, the spores survive and even the sterilizing process applied to evaporated milk may prove inadequate to render such milk completely sterile. Nor does the forewarming heat destroy all the vegetative forms of microorganisms. It kills a certain portion of them and the higher the count before heating the higher will it also tend to be after heating. It is more difficult to secure a low count after heating, in milk that was heavily contaminated before heating than in milk in which the count before heating was low.

Lack of sanitary care in the production of milk on the farm also tends to introduce a larger number of the more harmful types of bacteria in the milk. Unclean milking usually invites fecal contamination and unclean utensils generally introduce germs of the putrefactive type, many of which are highly heat-resistant. Even if the germs themselves are destroyed in the process of manufacture, their products formed before such destruction takes place, survive and may seriously jeopardize the quality and keeping properties of the finished goods. These facts emphasize the importance, not only of cleanliness, but also of prompt delivery of the milk to the factory. Their appreciation has led some factories to insist on receiving their fluid milk twice daily.

The relation of the composition and of fermentation products of milk to its heat-coagulation point are fully discussed in

Chapters XV and XXIII on "Factors that Influence the Heat Coagulation of Milk," and on "Composition and Properties of Milk," respectively.

Control of Quality.—Every well managed milk condensing factory plays the part of an educator in the production of sanitary milk. The condensery usually issues a set of rules, setting forth specifically the conditions under which the milk coming to the factory shall, or shall not be produced. Copies of these rules, which may be a part of the contract between condensery and patron, are placed in the hands of all patrons. The condensery employs one or more dairy inspectors whose business it is to see that the rules are rigidly enforced. These rules cover, in general, the following principal points:

1. Cows.—The milk must come from healthy cows. Milk from cows that are diseased, or that have a diseased udder, or that are otherwise in poor physical condition, will be rejected.
2. Feed and Water.—Do not feed weeds, roots, or other feed stuffs possessing strong and obnoxious odors, such as onions, garlic, turnips, cabbage, wet distillery slops, decayed, musty or sour silage, or other fermented feed.
3. Lactation Period.—Reject all milk from cows less than thirty days before, and the first seven days after calving.
4. Milkers and Milking.—Milk with clean, dry hands into clean utensils and remove the milk to the milk room immediately after drawn.
5. Straining.—Strain the milk in the milk room through a fine wire mesh strainer (80 to 100 meshes to the inch). Do not use cloth strainers.
6. Cooling.—Cool the milk to 60° F. or below and keep it at that temperature until it reaches the factory. Do not mix the warm morning's milk with the cold night's milk; cool the morning's milk before mixing, or send it to the factory in separate cans.
7. Care of Utensils.—Rinse with cold water, wash with warm water and washing powder, and rinse with boiling water all milk utensils thoroughly after use; keep them in a clean place between milkings, where they are exposed to air and sunlight.

Do not store the milk on the farm in cans that have not been washed by the factory.

8. Stables.—Whitewash the stable twice every year and remove manure daily. (Some condenseries furnish spray pumps for applying whitewash.)

INSPECTION OF MILK AT THE CONDENSERY

At the condensery the milk need be subjected to rigid inspection by a man who is, or should be, an expert on milk inspection; every can should be examined.

Inspection of Milk by Sense of Smell and Taste.—In most cases the milk is inspected with reference to odor. The inspector quickly raises the cover of each can to his nostrils. The odor in the cover is typical of that in the can. If it is "off," the can is rejected. An experienced man on the platform can, by the use of this method, tell with much accuracy, whether the milk should pass or not.

Inspection of Milk According to Its Temperature.—The temperature is also noted. This need not be done with the thermometer in each case. By placing his hand on the body of the can, or by noting the warmth of the air and odor in the cover immediately after removing it, or by observing the presence or absence of small particles of butter floating on the surface of the milk, the inspector can readily tell if the milk has or has not been properly cooled. A correct thermometer should always be on the platform for guidance.

Inspection of Milk by the Use of Acid Tests.—Titratable Acidity.—The fact that high-acid milk generally has a low heat coagulation point, has led to the adoption, in many condenseries, of the acid titration test as a means to determine the fitness of the milk for condensing purposes. The revelations of more recent researches, however, have demonstrated that the titratable acidity is not the only, and in many instances, not the dominating factor determining the behavior of milk toward the manufacturing process. It has further been pointed out that the titratable acidity is calculated as lactic acid, while the natural acidity of freshly drawn milk is due to factors other than lactic acid; that the natural acidity appears not to affect the heat coagulation point of milk and should, therefore, have no part in the determination of the fitness of milk for condensery purposes; that the natural acidity constitutes a large part of the titratable acidity in milk when it arrives at the factory and may in some cases be considerably above the maximum limit for titratable acidity set by the condensery; that it is the developed acidity and not the natural acidity, that lowers the stability of milk under heat treatment; that the titratable acidity, therefore, is not an accurate index to the fitness of milk for manufacure; and that to reject milk on the basis of an arbitrary limit of titratable acidity is an unjustifiable and unnecessary hardship to the producer and of little protection against manufacturing difficulties to the condensery.

Most of these assertions have a scientific background, they are the result of careful experiments. But they should not be interpreted as a conclusive recommendation to do away with the acid test on the milk receiving platform. The acid test by titration with a standard alkali is and remains a simple and helpful means for control. In the average milk from mixed herds the natural acidity is well below the usual acidity limit of the condensery, which is .18% acid. Only in exceptional cases does the natural acidity exceed this limit. In most cases of high acidity in mixed milk the excessive acidity is higher than it was in the freshly drawn milk. This means that it is due to fermentation acidity, to souring after the milk was drawn. It is well known that even a slight increase in the acidity from normal, causes a decided lowering of the temperature at which the milk will coagulate in the sterilizer.

This increased acidity above normal is controllable, it is preventable. It is due to not cooling the milk promptly after milking, or not cooling it to low enough a temperature, or to mixing warm morning's milk with the milk of the previous night, or to holding the milk too long, or to other neglect in its production and care on the farm. The acid test can be quickly made, it requires practically no technical training and, in spite of its limitations, its use is of assistance in the control of the quality of the milk received.

For reasons above enumerated, it is not advisable to depend on the acid test as the sole criterion of the quality of all milk received, and it may not be desirable to subject each can of milk to the acid test. But there is wisdom in adopting a definite standard of acidity for milk, provided that such a standard is applied judiciously. The practical condensery operator well knows that the nose and palate of the experienced inspector on the platform are better criterions than the acid test alone, as to the fitness of milk for condensing. But acid tests are most valuable in the case of uncertainty and suspicion as to the quality of any given can of milk. Milk that arrives too warm, or regarding the flavor and odor of which the inspector is uncertain and that tests .18 per cent of acid or more is usually unsafe milk for condensing.

It is obvious from this discussion that the acid titration test should not be depended upon as the sole basis for accepting or rejecting milk on the platform, but it may well serve as an index to the sanitary condition of the sources of milk, that should be looked into in an effort to determine whether any given case of high-acid milk is due to developed acidity resulting from improper care on the farm, or to natural acidity which has been found harmless to the stability of milk under heat treatment. For directions to make acid tests see Chapter XXXVII.

Hydrogen Ion Concentration.—The relation of the "true" acidity, as expressed by the hydrogen ion concentration, is discussed in detail in Chapter XV on "Factors that Influence the Heat Coagulation of Milk." Our present knowledge, though as yet very incomplete, suggests that the effect of the hydrogen ion concentration on heat coagulation varies with different types of milk. In general, an increase in hydrogen ions lowers heat stability, but in isolated cases the reverse may occur. According to Benton and Albery,[85] within the range of pH 6.58 and 6.65 the effect of variations in pH is negligible as compared with the effect of the salt balance. Outside of this range, however, changes in pH have a very marked and controlling effect on heat stability.

It appears doubtful that tests for the hydrogen ion determination on the receiving platform would constitute a more dependable guide as to the suitableness of the farmer's milk than the more simple tests available for the determination of the titratable acidity.

The Alcohol Coagulation Test.—The principle of this test rests on the presence or absence of coagulation of milk in a given quantity of alcohol of definitely known strength. The alcohol coagulation test responds to many of the known factors that influence the heat coagulation point, such as the salt balance, acidity, rennet-forming bacteria, colostrum, diseased udders, diseased cows, as shown by Sommer and Binney.[31] Its relation to heat coagulation is therefore somewhat closer than that of the acid test. Dahlberg and Garner,[30] as the result of applying the alcohol test in two evaporated milk factories, concluded that milk giving a positive alcohol test will, when concentrated into evaporated milk, coagulate more readily than alcohol-negative milk.

The subject of heat coagulation is discussed in detail in Chapter XV on "Factors that Influence the Heat Coagulation of Milk." The discussion shows the complexity of the problem, suggests the existence of factors as yet undetermined and unknown, and indicates lack of agreement among investigators on the influence and relationship of the known factors that affect heat coagulation of milk before and after concentration. It is not surprising therefore that there is also lack of agreement as to the value of the alcohol coagulation test as a dependable detector of milk on the receiving platform with reference to its heat coagulation stability after condensing.

Notwithstanding these uncertainties, it is a fact that the alcohol coagulation test has distinct merit as a rapid means of determining on the platform the fitness of milk for evaporated milk purposes. It is more positive than the acid test because more of the factors that influence the heat coagulation point do also influence the alcohol test in the same direction. It is not infallible, however, because of the complex and interfering reactions involved during the process of manufacture.

The alcohol test is a valuable help on the platform but, similarly as in the case of the acid test, it alone is not sufficient to serve as the sole basis upon which to accept or reject milk. It is of service in spotting such deliveries of milk as are most apt to cause trouble in the sterilizing process and thereby makes possible constructive investigation of the causes of such conditions at the source of production—on the farm. For detailed directions on the alcohol coagulation test see Chapter XXXVII.

The Phosphate Test.—This test was recently developed by Ramsdell, Johnson and Evans.[32] It is based on the relation of heat coagulation and coagulation of milk in the presence of mono-basic potassium phosphate (KH_2PO_4). This test is not intended to be used as a quality test of sanitary milk. Its chief aim is to aid in picking out those milks that impair the stability of the total composite during the seasons when sterilizing trouble is encountered. It is claimed by its authors to be more dependable in determining the heat coagulation stability of milk than the alcohol test. For detailed directions see Chapter XXXVII.

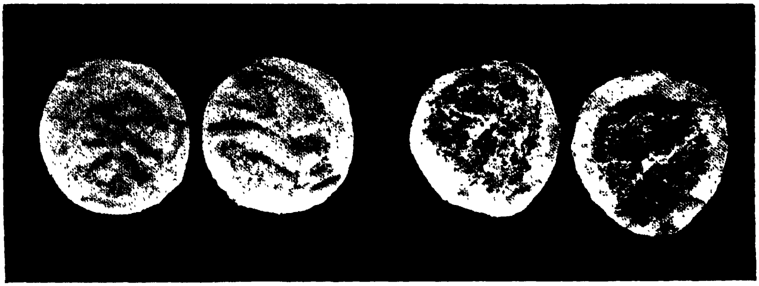
Fermentation Tests, The Methylene Blue Reduction Test, Microscopic Examinations and Plate Counts.—These tests have the purpose of revealing directly or indirectly the general trend of bacterial contamination of milk. They are not intended to determine the heat-coagulation resistance except in so far as microbe activity may influence the heat coagulation point of milk. Their chief purpose, however, is to furnish information on the quality of the milk as determined by the sanitary standard maintained in its production and handling on the farm.

The fermentation tests embrace the several curd tests. These show the presence or absence, extent and character of bacterial contamination by the visible changes produced in the condition of the milk constituents with particular reference to curd formation and character.

The methylene blue reduction test is a simple and practical demonstration of the extent of bacterial contamination by measuring the rapidity or length of time required for the removal of the oxygen dissolved in the milk, by bacteria when the milk is incubated at the optimum temperature for bacterial development. The direct miscroscopic count and the plate counts are direct bacteriological methods of determining the number of bacteria present.

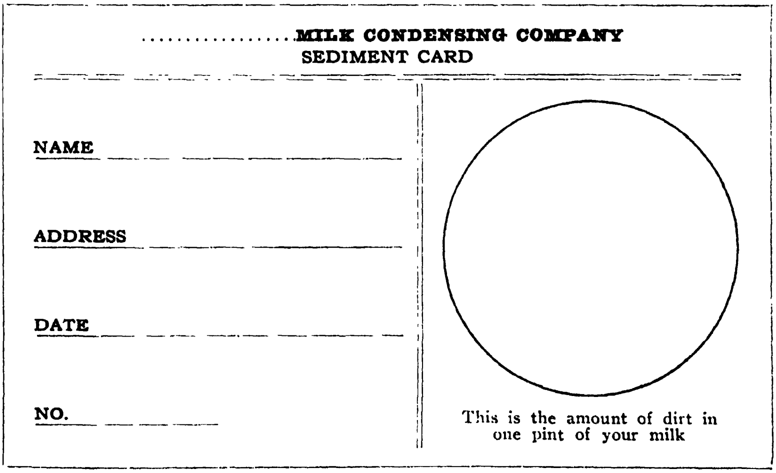
These several tests have distinct merit by furnishing a valuable index to the sanitary conditions under which the milk is produced on the farm. For detailed directions see Chapter XXXVII.

The Sediment Test.—This test shows the relative amount of dirt present in milk. One pint is passed through a small circle of absorbent cotton and the amount of mechanical impurities present in the milk is indicated by the color of the cotton after filtration. In order to hasten the filtration, the milk is forced through the filter under slight pressure. The mechanical construction of these testers has been greatly improved and their operation facilitated. If the cotton disc retains a white or creamy color, the milk is relatively free from filth. Milk produced under insanitary conditions stains the cotton brown or black.



Clean Milk **Fig. 10. Sediment tests** **Dirty Milk**

These cotton filters may be pasted on a sheet of paper similar to a milk sheet, arranged so that the circles are placed opposite the respective patron's name or number. When shown



.................**MILK CONDENSING COMPANY**
SEDIMENT CARD

NAME ____________________

ADDRESS ____________________

DATE ____________________

NO. __________

This is the amount of dirt in one pint of your milk

Fig. 11. Sediment test card

to the patrons who come to the factory, they furnish a most effective object lesson to them. When the milk reaches the factory on route wagons or by rail, cards similar to Fig. 11 may be mailed to the patrons. The evidence is so conclusive and convincing that even the most obstinate individual cannot help admitting his guilt and can usually be induced to "clean up."

FACTORY SANITATION

In the previous paragraphs, special emphasis was placed on the great importance of a good quality of fresh milk. It is equally essential that the factory be kept in exemplary condition as to cleanliness and sanitation. This is necessary because of its effect on the patrons and on the wholesomeness and marketable property of the finished product.

Effect on Patrons.—It does not take the watchful eye of the intelligent patron, who daily comes to the factory, very long to learn whether the manufacturer gives his milk as good care as he gave it on the farm. A good example set by the factory will mean much toward instilling the patron with ambition to do likewise on the farm. Shiftlessness is a contagious disease, to which the average farmer is susceptible. It would, therefore, be inconsistent for the factory to issue and attempt to enforce rules of sanitation for the dairy farmer while, within its own walls, the principles of sanitation are ignored.

Effect on Wholesomeness of the Product.—Uncleanliness and filth interfere with the wholesomeness of the product. Condensed milk made in a factory ignoring sanitation, may contain certain products of decay which are poisonous to the human system. Again, it may contain germs of infectious diseases and thus become the cause of widespread epidemics of these diseases and possibly claim many victims. The condensery's responsibility to the consuming public emphasizes the importance of close attention to the sanitary condition of all equipment and to sanitary precautions in manufacturing operations.

Effect on Marketable Properties of the Product.—Lack of cleanliness in the factory jeopardizes the market value of the finished product. It may lead to diminished keeping quality and cause heavy loss due to spoilage. Under certain conditions the absence of scrupulous cleanliness may even bar the product from desirable markets where health department regulations condemn it on grounds of high bacterial count, or presence of coli bacilli, etc.

Factory sanitation, embracing plant, equipment and operation, constitutes one of the controlling factors in the business success of the condensery. The important details of sanitary precautions as related to specific equipment and operations are discussed fully in connection with the use of the respective equipment and also in Chapters XXV and XXVI on "Condensed Milk Defects."

How to Keep the Factory in Sanitary Condition.—All equipment in which milk products are handled needs a thorough cleansing and sterilizing at the conclusion of its daily use. Tin plated equipment, such as tinned copper dump and weigh tanks, coil vats, sanitary lines, etc., are best rinsed with cold water, scrubbed with brush and hot water containing a suitable washing compound, flushed with clean hot water and steamed until "piping hot." Similar treatment applies likewise to chromium plated and glass enameled surfaces. Equipment in which milk is heated and which exposes to the milk surfaces of bare copper or other uncoated metal, such as kettles used for preheating and vacuum pans, need scouring with glass wool, sand paper, or emery cloth. In the case of the copper vacuum pan, particularly the inside of the dome and the goose neck, as well as the body, jacket and coils, thorough daily cleansing is required in order to avoid the formation and accumulation of copper oxide and copper salts readily soluble in the milk. All milk pumps, homogenizers, filling machines are natural enemies of sanitation. They are best kept clean by pumping hot alkali water through, taking them apart for rinsing and sterilizing, and reassembling them just before use. In the case of the filling machine for sweetened condensed milk, daily washing is unnecessary, but it should be dismantled and completely washed once each week, and protected from flies and dust by covering when not in use.

Each morning all equipment should again be flushed out with hot water and steamed before the milk is allowed to circulate. If the sterilizing is done by the use of a chlorine solution instead of steam, the chlorine treatment should be followed by a hot water rinse.

Where the cooling of sweetened condensed milk is done in cans revolving in vats filled with water, the cooling water in these vats needs attention; it should be replaced with fresh water daily. The sugar chute requires daily inspection, seeing to it that no damp or fermenting sugar is crusting its interior. The stock supply of empty tins demands protection against defilement from dirt, dust, insects and rodents; whenever possible the tins should be sterilized before use.

Sanitation of the factory rooms is of paramount importance. The floors need removal of accumulations of rubbish and a daily scrubbing and flushing; the drains and sewers need a dose of an efficient disinfectant at reasonable, regular intervals. Walls and ceilings in factory and cold rooms should be kept free from mold by treatment with a solution of a suitable disinfectant when needed.

Can Washing.—Another extremely important, and too often neglected feature, relating to the effective management of the patron from the standpoint of high quality of milk, is the condition of the milk cans which the factory returns to the patron. The patron is bound to lose interest in taking painstaking care of his milk when the cans returned to him by the factory are filthy and foul-smelling. It is obvious that the quality and

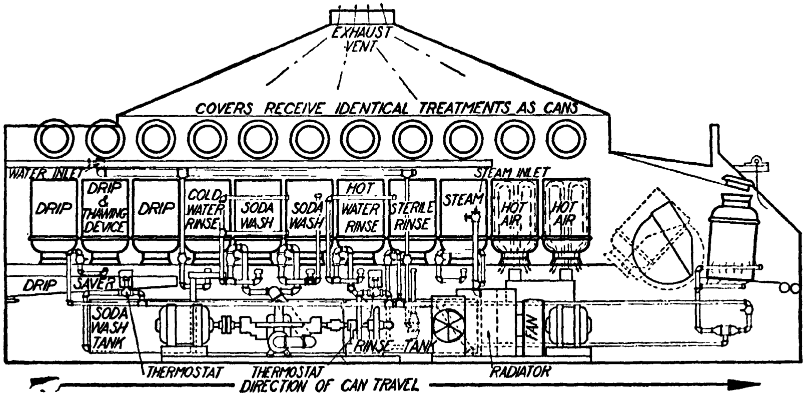


Fig. 12. Mechanical can washer
Courtesy of Lathrop-Paulson Co.

wholesomeness of milk held and transported in such cans are jeopardized.

Proper can washing consists of four essential operations, namely, washing, rinsing, steaming and drying. The cans should be washed until all remnants of milk are removed. They should be rinsed with hot water until all of the dirty wash water is flushed out. They should be steamed until "piping-hot," and they should be dried until "bone-dry."

There is now admirable equipment available on the market for accomplishing these four important purposes, affording adequate facilities to enable the condensery to return to the patron cans that are clean, sterile and dry.

Care of Milk in the Factory Prior to Manufacture.—The problem of so handling the milk in the factory, from the time it arrives until it is heated preparatory to evaporation, is an important one that has received much careful consideration by the foremost condensed milk men. Under favorable temperature conditions, the micro-organisms present in milk multiply rapidly, doubling in number once every twenty minutes. It is essential therefore, that the milk either be heated to high enough temperatures to destroy germ life, or cooled to a temperature low enough to stop growth and multiplication, as soon as possible.

From the standpoint of storage tank requirements and quality of finished product the system of running the milk directly

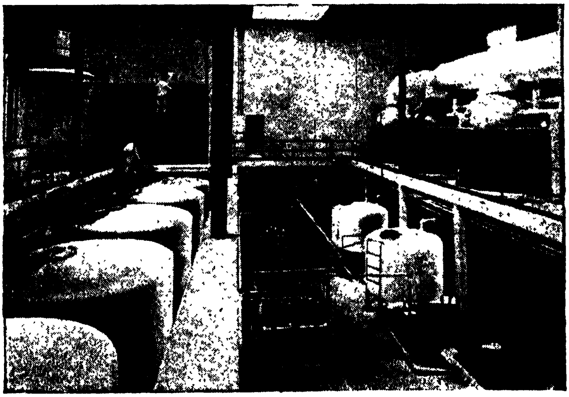


Fig. 13. Glass-lined milk storage tanks
Courtesy of The Pfaudler Company

from the weigh cans into hot wells for prompt heating is preferable. Where this arrangement and procedure are not feasible and the milk has to be held a considerable length of time before it can be heated, there is need for adequate facilities to cool it and keep it cool until needed. In such cases the milk flows from the receiving platform over surface coolers into holding tanks or it runs direct into holding tanks equipped with coils or jacket where it is cooled, preferably to about 45° F., and kept cool while it remains there. The use of storage tanks for the fluid milk has the further advantage of facilitating the standardization of milk for fat and solids not fat.

PART II

Manufacture of Sweetened Condensed Milk

CHAPTER IV.

PREPARING THE MILK FOR CONDENSING

Sweetened condensed milk is cow's milk, condensed at the ratio of 2⅓ to 2¾ parts of fresh milk to 1 part condensed milk. It contains considerable quantities of sucrose, or part sucrose and part dextrose, usually about 40 to 45 per cent, to preserve it. It is of semi-fluid consistency and reaches the market in hermetically sealed tin cans, varying in size from eight ounces to one gallon, and in barrels similar to glucose barrels, holding from three hundred to seven hundred pounds of condensed milk. When made properly, sweetened condensed milk will keep for many months, but is best when fresh.

General Description of Equipment Needed and Process Used.—The equipment required and the flow of the milk from weigh tanks on milk receiving platform to filling machine for finished product are diagrammatically illustrated in Fig. 14. The assemblage of equipment shown is not intended to be complete in every detail of accessories, nor is each apparatus contained therein necessarily most suitable in type, size and arrangement under all conditions. It does represent, however, a general conception of a practical "line-up" of equipment adapted to the manufacture of sweetened condensed milk.

From weigh tanks (A) the fluid milk flows over a cooler (B) into holding tanks (C) where it is standardized to the desired proportion of per cent fat and solids not fat. It may be found desirable to install a milk filter or clarifier between weigh tanks and cooler. From the holding tanks the standardized milk is pumped by pump (E) into milk supply tank (D) from which it flows by gravity through forewarmer (F) and superheater (G) into sugar mixer (H). The superheater is a new innovation,

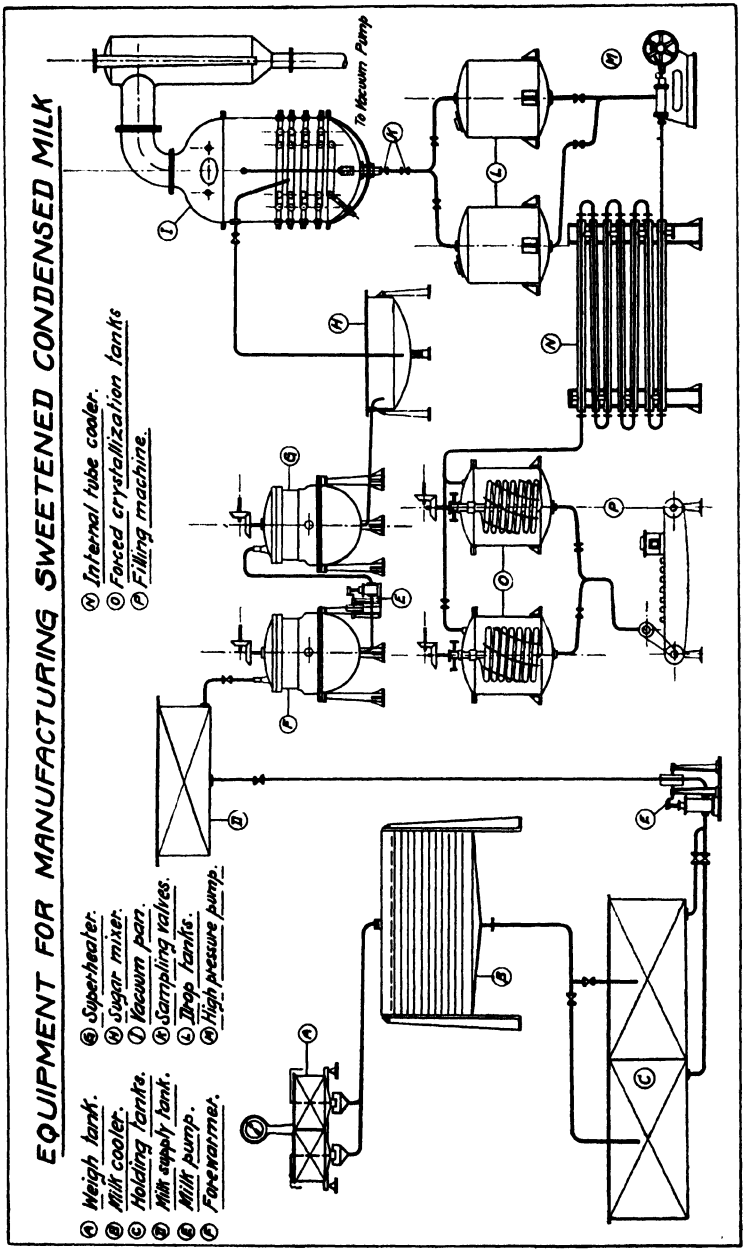


Fig. 14. Flow-sheet for manufacture of sweetened condensed milk

not as yet found in American condenseries, but its use has promising possibilities from the standpoint of controlling progressive thickening of sweetened condensed milk, as discussed later in this chapter and in Chapters XXIII and XXV.

From the sugar mixer (H) the milk enters the vacuum pan (I) and the condensed milk drops through sampling valves (K) into drop tanks (L) where it may be standardized for total solids. These drop tanks might conveniently rest on scales so as to facilitate the determination of the exact weight of each batch.

The standardized sweetened condensed milk is then forced by pressure pump (M) through cooling coils (N). The cooling coils are either of the internal-tube cooler type, similar to an

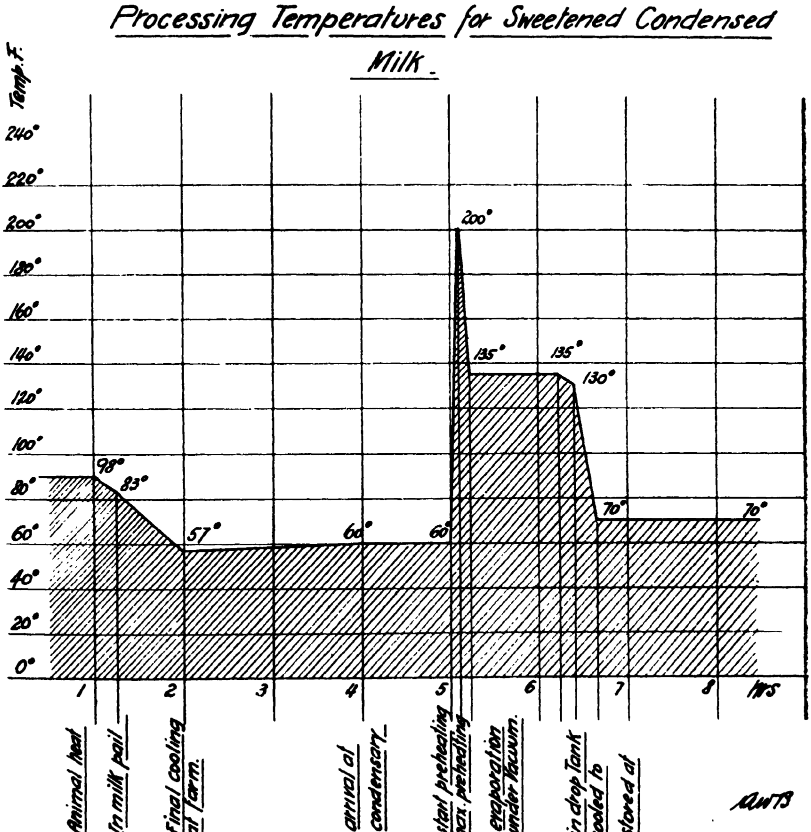


Fig. 15. Sweetened condensed milk temperature flow-sheet

ammonia condenser, or they may be submerged in a tank through which the cooling water circulates. The cooling coils discharge the condensed milk into the forced-crystallization tanks (O) and from here it drops into the filling machine (P) where the tins are filled and sealed. The temperatures to which the milk is exposed in its journey from cow to sealed tin are shown in graph Fig. 15.

Weighing, Filtering, Cooling and Standardizing the Fluid Milk.—The fluid milk, after inspection on the receiving platform, is "dumped" through milk strainers into the weigh tanks on scales. Here each patron's milk is sampled for fat test, weighed and then filtered over a cooler and run into holding tanks. These tanks, as soon as filled, are sampled, the percentages of fat and solids not fat are determined and the milk is standardized to the desired proportion of fat to solids not fat as described below.

Standardizing.—In the manufacture of sweetened condensed milk of definite percentage composition, it becomes necessary first to standardize the fluid milk to the desired ratio of fat to solids not fat; then to calculate the amount of sucrose to be added in order to obtain the desired ratio of sucrose to total milk solids. After condensing the finished product is finally standardized to the desired percentage of total solids by the addition of water, if necessary.

When the desired amount of milk has reached the holding tanks and it has been tested for fat and solids, it is standardized to the correct ratio by one of the following methods:

1. Correcting Fat Shortage

Example.—Sweetened condensed milk containing 8 per cent fat and 20 per cent solids not fat is wanted.

Fluid milk in batch, 7000 lbs., 3.3% fat and 9% solids not fat.

Cream available, testing 25% fat and 6.7% solids not fat.

How much of this cream must be added to the original milk?

Answer:

Desired ratio of fat to solids not fat is 8 : 20 or 1 : 2.5.

7000 lbs. milk testing 3.3% fat contain $\frac{7000 \times 3.3}{100} = 231$ lbs. fat.

7000 lbs. milk testing 9.0% solids not fat contain $\frac{7000 \times 9}{100} =$ 630 lbs. solids not fat.

At the ratio of 1 : 2.5, the 231 lbs. of fat in the original milk requires $231 \times 2.5 = 577.5$ lbs. solids not fat.

Surplus of solids not fat in original milk is $630 - 577.5 = 52.5$ lbs.

To balance this surplus, cream testing 25% fat and 6.7% solids not fat is to be added as shown by the following calculation:

1 lb. of fat must standardize 2.5 lbs. solids not fat

1 lb. 25% cream standardizes $\frac{2.5 \times 25}{100} = .625$ lbs. solids not fat

1 lb. of 25% cream contains .067 lbs. solids not fat

Each lb. of 25% cream will balance .558 lbs. solids not fat

Surplus of solids not fat in original milk is 52.5 lbs.

Amount of 25% cream to add, therefore is $\frac{52.5}{.558} = 94.08$ lbs.

Proof:

7000 lbs. original milk contain 231.00 lbs. fat and 630.0 lbs. S.N.F.

94.08 lbs. 25% cream contain 23.52 lbs. fat and 6.3 lbs. S.N.F.

7094.08 lbs. total batch contains 254.52 lbs. fat and 636.3 lbs. S.N.F.

Ratio of fat to solids not fat is 254.52 : 636.3 = 1 : 2.5.

Per cent fat in standardized milk is $\frac{254.52}{7094.08} \times 100 = 3.588\%$

Per cent S. N. F. in standardized milk is $\frac{636.3}{7094.08} \times 100 = 8.973\%$

Per cent T. S. in standardized milk $= 12.561\%$

The above standardizing formula is accurate and simple, and applicable to all cases where there is a fat shortage in the original milk.

2. Correcting Fat Surplus

Example—Sweetened condensed milk containing 8% fat and 20% solids not fat is wanted.

Fluid milk in batch, 7000 lbs., 4% fat and 8.5% solids not fat.

Skimmilk available, testing 0.2% fat and 9% solids not fat. How much skimmilk must be added to the original milk?

Answer:

Desired ratio of fat to solids not fat is 8 : 20 = 1 : 2.5.

7000 lbs. milk contain $\frac{7000 \times 4}{100} = 280$ lbs. fat.

7000 lbs. milk contain $\frac{7000 \times 8.5}{100} = 595$ lbs. solids not fat.

At the ratio of 2.5 : 1 the 595 lbs. of solids not fat in the original milk require $\frac{595}{2.5} = 238$ lbs. of fat.

Surplus of fat in original milk is 280 — 238 = 42 lbs.

To balance this surplus, skimmilk testing 9% solids not fat and 0.2% fat is to be added, as shown by the following calculation:

1 lb. of solids not fat must standardize $\frac{1}{2.5} = .4$ lbs. fat.

1 lb. of skimmilk (9% S.N.F.) will standardize
.4 × .09 = .036 lbs. fat
1 lb. of skimmilk contains 0.2% or = .002 lbs. fat
Each lb. of skimmilk (9% S. N. F.) will balance
.036 — .002 = .034 lbs. fat

Surplus of fat in original milk is 42 lbs.

Amount of skimmilk to add, therefore, is $\frac{42}{.034} = 1235$ lbs.

Proof:

7000 lbs. original milk contain 280.00 lbs. fat and 595.00 lbs. S.N.F.
1235 lbs. skimmilk contain 2.47 lbs. fat and 111.15 lbs. S.N.F.
8235 lbs. total batch contains 282.47 lbs. fat and 706.15 lbs. S.N.F.

Ratio of fat to solids not fat is 282.47 : 706.15 = 1 : 2.5.

Per cent fat in standardized milk is $\frac{282.47}{8235} \times 100 = 3.430\%$

Per cent S. N. F. in standardized milk is $\frac{706.15}{8235} \times 100 = 8.575\%$

Per cent T. S. in standardized milk = 12.005%

This standardizing formula will apply to all cases of excess fat in the original milk.

FOREWARMING

Purpose.—The first step in the process of manufacture is to heat the milk to a temperature sufficiently high to destroy bacteria, yeasts, molds and enzymes. Forewarming also assists in the solution of the sucrose and in preventing the milk from burning on to the heating surface in the vacuum pan.

Forewarming Destroys Ferments.—The milk received at the factory contains a varying flora of diverse species of ferments, both organized and unorganized. Some of the ferments are known to be harmless, while others are capable of causing fermentation changes damaging to the marketable properties of the finished product. There is also always the possibility of the presence of germs of milk-borne diseases, the destruction of which depends on the forewarming temperature of the milk.

The usual temperature range at which the milk is condensed in the vacuum pan (130 to 145° F.) is not sufficiently high to insure destruction of quality-damaging micro-organisms and enzymes and of germs of disease such as might be present. No other part of the process of manufacture exposes the milk to high temperature. The biological purity of the finished product, as far as the contaminating agencies of the fluid milk are concerned, therefore depends on the germ killing efficiency of the process of forewarming. The lowest forewarming temperature that will inactivate damaging milk enzymes is 75° C (167° F). This temperature will also destroy the great majority of non-spore bearing bacteria, yeasts and molds.

Forewarming Assists Solution of Sucrose.—In factories that dissolve the added sucrose in the milk, which is the most common practice, rapid and complete solution is facilitated by forewarming. This is important because the passage of undissolved sugar crystals into the vacuum pan, especially toward the end of the condensing process, invites the development of large crystals and coarseness in the finished product.

Prevention of Burning Milk on Heating Surface.—If cold milk comes in contact with a steam-heated surface and is not agitated vigorously, it bakes or burns onto this heating surface. The milk in the vacuum pan is heated or kept hot by means of the steam jacket and coils. These radiators are charged with steam under pressure and consequently give off a high degree of heat. If cold milk is drawn into the vacuum pan, the milk remains at rest for a considerable length of time. During this time it is bound to bake or burn on the heating surface, giving the product a burnt flavor, causing it to contain brown specks and retarding the process of evaporation. If the milk is hot when it enters the pan, the reduced pressure in the pan causes it to boil violently at once, avoiding all danger of sticking to and burning on the heating surface, and making possible maximum rapidity of evaporation.

Temperature of Forewarming.—In condensery practice the forewarming temperatures used extend over a wide range, from pasteurization by the holding process at 145° F, to super-heating the milk at 105 to 110° C (221-230° F) with steam under pressure. In most American condenseries the milk is heated to near the boiling point (185 to 210° F).

The temperature of forewarming plays an important role in the control of the physical stability (progressive thickening) of the finished product. This was first experimentally shown by Rogers, Deysher and Evans,[33] and later by Leighton and Deysher[34] and Stebnitz and Sommer.[35] Their results indicate that, other conditions being equal, forewarming temperatures between about 85° C (185° F) and the boiling point yield the least stability and cause most rapid and most pronounced thickening of the condensed milk after manufacture, while temperatures both below 185° F and considerably above the boiling point greatly improve the stability and lessen the thickening tendency.

Adjustment of the forewarming temperature should take into consideration also its relation to the keeping quality of the finished product from the standpoint of possible deterioration due to biological causes. Our present knowledge, taking into consideration the effect of the forewarming temperature on both the physical stability and the biological keeping quality, suggests that a forewarming temperature range of 75 to 85° C (167-185° F) offers the greatest assurance of maximum physical stability consistent with adequate protection of the condensed milk from keeping quality-destroying ferments, provided the milk is heated to such temperatures before any sugar or remnants of previous batches of condensed milk are added to it.

Temperatures above the boiling point (230-250° F) would offer additional advantages from the standpoint of maximum ferment-destroying efficiency without diminishing the physical stability of the product, and wherever mechanically and economically feasible this higher range of forewarming temperatures appears desirable. For detailed discussion on thickened and rancid sweetened condensed milk see Chapter XXIII on "Composition and Properties of Milk," and Chapter XXV on "Defective Sweetened Condensed Milk."

Method of Heating.—Control of temperature, speed, freedom from objectionable scorching of the milk and economy of fuel are important prerequisites of a satisfactory method of forewarming. There appears to be no set standard of equipment and no method that has been universally adopted.

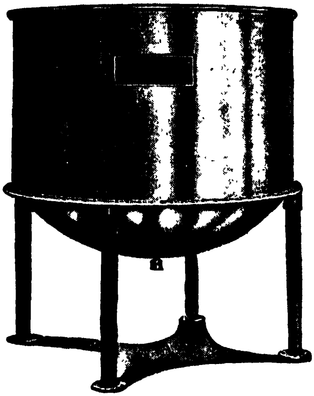


Fig. 16. Hot well for heating with "live steam"
Courtesy of Arthur Harris & Co.

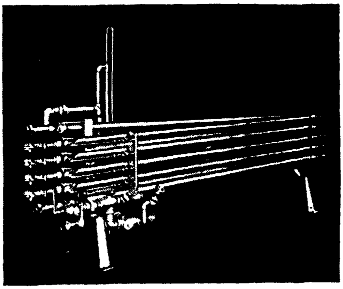


Fig. 17. Multijet continuous-flow heater
Courtesy of Cherry-Burrell Corp.

The oldest equipment is the copper hot well in which "live" steam is blown directly into the milk through a perforated steam rosette near the bottom of the hot well, which distributes the steam radially in the form of fine jets. This system is still in use in many factories. In other factories the forewarming is done in jacketed kettles with revolving agitator, or by the use of continuous-flow heaters, or by various combinations of heating equipment and methods.

In the United States the combination of steam jacketed kettle and steam rosette is gaining in favor. The milk is heated to about 160° F by the steam jacket and the forewarming is finished with live steam. By this method the objectionable dilution of the milk with condensed steam is minimized without appreciably sacrificing the speed of heating. In some of the European factories the forewarming is completed by superheating the hot milk in a closed kettle with revolving agitator, raising the temperature under pressure to from 105 to 120° C (221 to 248° F) before the milk reaches the sugar mixer and vacuum pan. Such a superheater is shown in Fig. 19.

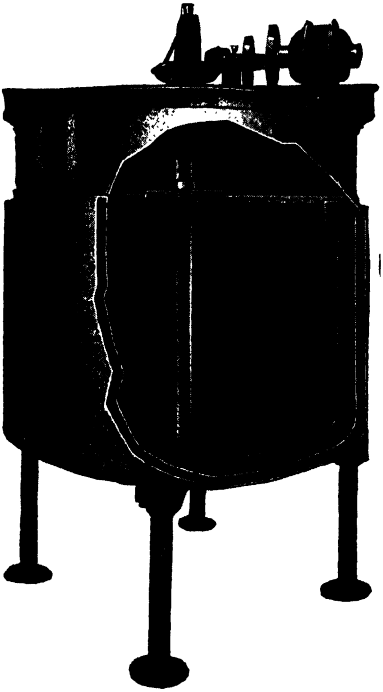


Fig. 18. Jacketed hot well with agitator
Courtesy of C. E. Rogers Co.

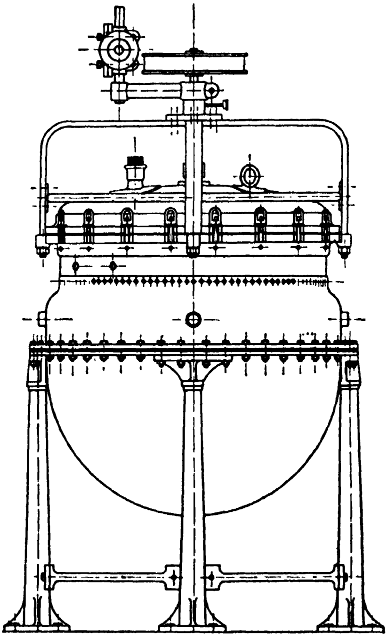


Fig. 19. Superheater hot well
Courtesy of A. W. Baumann

Steam Requirements for Forewarming 1000 lbs. of Milk by Injecting "Live" Steam into the Milk.

Example:

Initial temperature of milk is 50° F.
Forewarming temperature is 190° F.

Specific heat of milk is .93 B.T.U.
Pressure of saturated steam is 100 lbs.

Calculation:

Heat units required to raise temperature of milk from 50° F. to 190° F. = $(190 - 50) \times 0.93 \times 1000 = 130{,}200$ B.T.U.

Heat units in 1 lb. saturated steam at 100 lbs. pressure (see Table 10) is 1190.6 B.T.U.

Sensible heat in 1 lb. saturated steam at 100. lbs. pressure (see Table 10) is 308.3 lbs.

The full utilization of this sensible heat requires cooling to 32° F. Since the starting temperature of the milk is 50° F., only part utilization of the sensible heat of the steam is possible. In this case the difference between heat units available and heat units utilized is 50 — 32 = 18° F., so instead of 308.3 B.T.U., only 308.3 — 18 = 290.3 B.T.U. are utilized.

By finishing the forewarming at 190° F., 190 — 32 = 158 B.T.U. are utilized. Assuming that the average temperature of starting and finishing is the arithmetical average of the true extreme figures, the heat units utilized then are $\frac{290.3 + 158}{2} = 224.3$ B.T.U. For each pound of steam condensation, therefore, only 224.3 B.T.U. of the 308.3 B.T.U. of sensible heat is utilized.

Hence the heat units not utilized is 308.3 — 224.3 = 84 B.T.U.

The total utilization of heat units per pound of steam at 100 lbs. pressure, therefore, is 1190.6 — 84 = 1106.6 B.T.U.

Lbs. steam required to forewarm the 1000 lbs. of milk is $\frac{130{,}220}{1106.6} = 118$ lbs.

It requires 118 lbs. of saturated steam at 100 lbs. pressure to heat 1000 lbs. of milk from 50 to 190° F., or .118 lbs. of steam per pound of milk.

In practice the steam requirements are slightly greater due to heat loss by radiation. Also, where steam at lower pressure is used, the amount of steam required is correspondingly greater.

Increase in Volume of Milk Due to Steam Condensation.— When forewarming with "live" steam injected into the milk, the steam condensation is added to the milk. Using the calculations of the above example, the volume of milk is increased from 1000 lbs. to 1000 + 118 = 1118 lbs. This represents an increase in volume of milk to be evaporated of 11.8%. With lower pressure steam, more steam is required, hence the volume of extraneous water thus added is proportionately greater. In practice this increase in volume of milk amounts to approximately 16%.

Steam Requirements, when Using Jacketed Forewarmers.—When using the steam-jacketed forewarmer the amount of steam required is slightly greater than when forewarming by injecting "live" steam directly into the milk. This is due to non-utilization of the sensible heat of steam condensation. By using steam traps whereby the steam condensation returns to the boiler, the steam requirements for both systems of forewarming are practically the same.

However, the use of the jacketed forewarmer, or any other heater that does not add the steam condensation to the milk, is far more economical from the standpoint of total steam requirements for condensing, because it eliminates the addition to the milk of a large volume of water such as is unavoidable where the steam is injected into the milk. The evaporation of the thus added water increases the amount of steam necessary to condense a given volume of milk to the desired concentration; it increases also the volume of water needed to supply the condenser; and it prolongs the time required for condensing the batch of milk. Park,[37] who conducted comparative tests, found that in changing from heating with "live" steam to forewarming by steam heated metal surfaces reduces the time required for condensing a batch of 9,000 pounds of evaporated milk at least 10 minutes.

An additional objection to forewarming by the use of "live" steam has to do with impurities with which the steam is often associated, such as cylinder oil from engine and steam pumps, boiler compounds used in the boiler, scale from the inside of the steam pipes, all of which may jeopardize the quality of the finished product. Whether and to what extent the heating of milk with live steam affects the marketable properties of the condensed milk has not been definitely determined. However, our present knowledge which is largely confined to observations and experiences in commercial manufacture, suggests that the effect, if any, is negligible.

ADDITION OF SUGAR

Kinds of Sugar.—Sugar is added to the condensed milk for the purpose of preserving the milk without the necessity of sterilization by heat. The sugar used, therefore, must have known preservative properties. It must not be readily fermentable, it must have the power of inhibiting bacterial activity when present in solution of such concentration as is suitable for a marketable condensed milk.

Sucrose.—Saccharose, $C_{12}H_{22}O_{11}$, when properly refined, ferments with difficulty in concentrated solutions. It has the power of retarding the growth of bacteria and other ferments ordinarily present in sweetened condensed milk. It has, therefore, been found highly suitable and is almost exclusively used for this purpose in the manufacture of sweetened condensed milk.

Cane Sugar and Beet Sugar.—The sucrose of commerce suitable for this purpose is highly refined cane sugar and highly refined beet sugar.

Beet sugar, which is chemically identical with cane sugar, is used in European countries very largely in the place of cane sugar. On the continent the beet sugar industry is an important factor. With the climate adapted to the growing of sugar beets and the labor relatively cheap, beet sugar can be secured by the European condenseries at lower cost than cane sugar. In America, where the annual sugar cane crop is large and where the high cost of labor renders the expense of growing sugar beets relatively high, there is practically no difference between the price of cane sugar and beet sugar.

The use of corn sugar in food products in which sugar is a recognized element was legalized, without declaration on the label, by the Food and Drug Administration of the United States Department of Agriculture under date of December 26, 1930.

This concession places the use of corn sugar within reach of the American manufacturer of condensed milk. Corn sugar or refined dextrose, as now offered on the market under the trade name "Refined Cerelose," thus promises possibilities of application in the manufacture of sweetened condensed milk. It is available at lower cost, it is about one-third less sweet, it is more digestible and more readily assimilated than sucrose and its substitution of at least a portion of the sucrose in an important food product such as condensed milk is looked upon with favor by the medical profession. For detailed discussion of the suitability and use of dextrose in the manufacture of sweetened condensed milk see Chapter X on "The Use of Corn Sugar in the Manufacture of Sweetened Condensed Milk."

Quality of the Sugar.—Since the sugar, sucrose, is added for the purpose of preserving the condensed milk, it is obvious that none but the best quality of refined sucrose is admissible. Low grade sucrose is a product dangerous to the condensed milk business. It is apt to contain sufficient quantities of acid and invert sugar, to give bacteria and yeast an opportunity to start fermentation. When once started, the destruction of the product is almost inevitable.

It is very important that the sugar in the factory be stored where it will keep dry. Sucrose has hygroscopic properties. When exposed to an atmosphere of high humidity it absorbs moisture. In damp storage it is prone to become lumpy, moldy and frequently sour. When these precautions are neglected there is danger of defective condensed milk, causing the cans on the market to swell, due to gaseous fermentation.

Adulteration of sugar with foreign admixtures, such as white sand, white clay, starch or lime dust is rare, and occurs usually only in pulverized sugar. For the detection of these adulterants add a spoonful of the suspicious sugar to a glass of hot water and stir. Pure sugar will dissolve completely, while most of the common impurities are insoluble and will settle to the bottom. The purchase of coarsely granulated sugar largely eliminates the danger of the presence of such adulterants. Powdered sucrose should not be used in the condensery.

Amount of Sugar.—The amount of sugar added normally varies within the range of about 14 to 20 pounds per 100 pounds of fluid milk. The principal factors controlling the amount of sugar to use are the desired composition of the finished product and the composition of the fluid milk.

If the added sugar is to fulfill its intended purpose it must be present in such concentration in the condensed milk as to prevent bacterial spoilage. Long experience in manufacture has shown that under normal conditions this is accomplished when the sugar-in-water ratio in the condensed product is approximately 62.5%. A lower sugar-in-water ratio is insufficient to insure dependable inhibition of the various types of bacteria normally present.

The above sugar concentration, however, will not prevent the damaging development of yeast and mold, if such contamination is present. It is insufficient also to absolutely protect the condensed milk against bacterial thickening. Condenseries that are troubled with bacterial thickening will find a somewhat higher sugar concentration helpful. A sugar-in-water ratio of approximately 64 to 64.5% is usually sufficient to control the type of bacteria responsible for this defect, unless they are present in abnormally large numbers and in invigorated form.

The problem of controlling abnormal fermentations such as yeasty fermentation, mold growth and abnormal bacterial thickening, however, is not one of sucrose concentration; it has to do very largely with lack of sanitation, and its successful and permanent solution lies in efforts to prevent such contamination through improved factory sanitation.

A sugar-in-water ratio of 64.5% approaches the saturation point of sucrose. Increasing the sugar-in-water ratio beyond this point is undesirable from the manufacturing standpoint because, when such milk is stored at low temperatures for any length of time, there is danger of coarseness due to the formation of cane sugar crystals.

From the standpoint of the consumer, also, an unnecessarily high sucrose content is objectionable. Sweetened condensed milk is regarded and serves as a substitute for milk. The more sucrose it contains the less does it resemble the composition and properties of normal milk. Milk is looked upon as a well-balanced food. The addition to it of large amounts of sucrose destroys this equilibrium, rendering it excessively rich in carbohydrates and relatively poor in proteins. Likewise, sucrose is less digestible than the several natural constituents of milk. These considerations are significant especially when condensed milk is used for infant feeding and in the diet of persons with weak digestion.

Table 3 shows the percentage of sucrose required in condensed milk and condensed skimmilk of varying percentages of total milk solids in order to maintain a sugar-in-water ratio of 62.5%. The figures also indicate the pounds of sugar that must be added per 100 pounds of fluid milk. These figures are based on an average of 12 per cent total solids in the fluid whole milk and of 9.0 per cent in the fluid skim milk.

Table 3.—Sweetened Condensed Whole Milks and Sweetened Condensed Skimmilks with a Sugar-in-Water Ratio of 62.5% Amount of Sugar to Add per 100 lbs. of Fluid Milk

Condensed Whole Milk			Condensed Skimmilk		
Total Milk Solids in Condensed Milk Percent	Sucrose in Condensed Milk Percent	Sugar to add per 100 Lbs. of Fluid Whole Milk Pounds	Total Milk Solids in Condensed Skimmilk Percent	Sucose in Condensed Skimmilk Percent	Sugar to add to 100 Lbs. Skimmilk Pounds
28	45.00	19.3	24	47.50	17.79
29	44.38	18.4	25	46.88	16.86
30	43.75	17.5	26	46.25	16.00
31	43.13	16.7	27	45.63	15.21
32	42.50	15.9	28	45.00	14.44
33	41.88	15.2	29	44.38	13.78
34	41.25	14.7	30	43.75	13.13
35	40.63	13.9	31	43.13	12.52
36	40.00	13.3	32	42.50	11.95

The present Federal Standards in the United States require sweetened condensed whole milk to contain not less than 28 per cent total milk solids and sweetened condensed skimmilk not less than 24 per cent milk solids. Table 3 shows that when confining the milk solids in the condensed milk to the above minimum requirements and desiring a sugar-in-water ratio of 62.5% in the finished product, the amount of sugar to be added per 100 pounds of whole milk containing 12% total solids is 19.3 pounds, and the amount of sugar to be added per 100 pounds of skimmilk containing 9% milk solids is 17.8 pounds. On the basis of the above additions of sugar, the sucrose content in condensed whole milk with 28% total milk solids is 45%, and in the condensed skimmilk with 24% milk solids it is 47.5%.

Most foreign brands show a similar sugar-in-water ratio, (approximately 62.5%), but their ratio of concentration generally is higher, causing the condensed milk to contain a higher percentage of milk solids and a lower percentage of cane sugar.

Calculation of Amount of Sugar to Add.—The desired amount of sugar to add is calculated from the ratio of the percentages of the total milk solids and sugar desired in the finished products.

Example.—Using the standardized milk of Example 1, as given previously in this chapter under "Standardizing," it is desired to have the finished product contain 44 per cent sucrose and 28 per cent milk solids.

Standardized fluid milk in batch 7094 lbs.

Per cent milk solids in batch 12.56%.

How much sugar must be added to the milk in order to have the finished product contain 44% sucrose when the milk has been condensed sufficiently to contain 28% milk solids?

Answer:

Ratio of milk solids to sucrose is 28 : 44 = 1 : 1.57.

Standardized milk contains 12.56% milk solids.

Amount of sugar to add per 100 lbs. of standardized milk is

$$12.56 \times 1.57 = 19.72 \text{ lbs.}$$

Amount of sugar to add to batch is $\frac{7094 \times 19.72}{100} = 1398.9$ lbs.

Proof:

Total milk solids $\frac{7094 \times 12.56}{100} = 891$ lbs.

$$891 \times 1.57 = 1398.9 \text{ lbs. sugar.}$$

If a given sugar-in-water ratio is desired in the finished product the calculations are as follows:

Deduct the per cent milk solids desired in the condensed milk from 100. This gives the total percentage of sugar and water present in the condensed milk. Multiply this by the sugar-in-water ratio and divide by 100. This gives the per cent of sugar present in the condensed milk. Multiply this by the per cent total solids in the fluid milk and divide by the per cent milk solids in the condensed milk. This gives the pounds of sugar that must be added to each 100 pounds of fluid milk.

Example.—A sugar-in-water ratio of 62.5% is desired. The fluid milk contains 12% total solids and the condensed milk must contain 30% milk solids. How many pounds of sugar must be added per 100 pounds of fluid milk?

Answer:

$100 - 30 = 70\%$ total sugar and water in condensed milk.

$\frac{70 \times 62.5}{100} = 43.75\%$ sugar in condensed milk.

$\frac{43.75 \times 12}{30} = 17.5$ pounds sugar to be added to each 100 pounds fluid milk.

Dissolving the Sugar.—The sucrose is added either to the hot milk before the milk enters the vacuum pan, or it is dissolved separately in boiling hot water. Enough water is used to secure a concentrated sugar solution (about 60%) and this syrup is then drawn into the pan with the milk.

The general practice in American condenseries is to dissolve

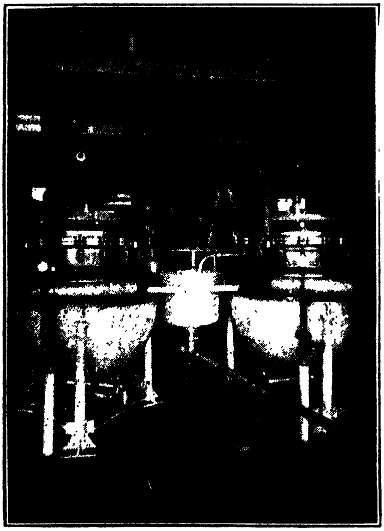


Fig. 20. Superheater hot wells

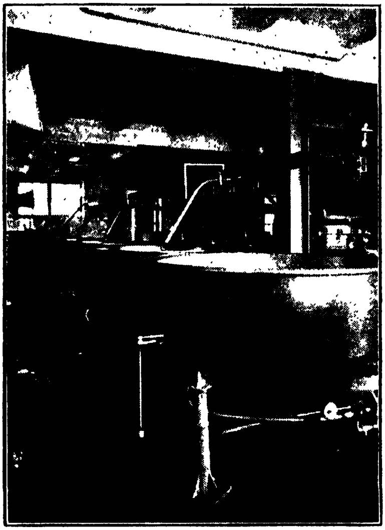


Fig. 21. Sugar mixers

Condensery of Berner Alpen Milch Gesellschaft

Courtesy of A. Baumann & Co., Thun

the sugar in the hot milk. It has the advantage of eliminating the drawing of extraneous water into the pan, which must be evaporated. It is important to allow the milk to reach the full forewarming temperature before the sugar or remnants of condensed milk, if there are any, are added to it. It has been shown by Rice[36] that the presence of sucrose in the milk renders the enzyme lipase more resistant to heat and that lipase is the cause of rancidity in sweetened condensed milk. This protective influence of the sugar may extend to other enzymes and even to micro-organisms as well. Adding the sugar after the milk has reached the maximum forewarming temperature insures destruction of the lipase and other enzymes and harmful non-spore forming bacteria and yeast that may be present in the milk.

The practice of dissolving the sugar separately in water and drawing this syrup into the pan eliminates the possibility of the presence of sucrose in the milk while forewarming. It has the further advantage of permitting the boiling of the sugar solution without jeopardizing the physical stability (progressive thickening) of the product after manufacture. It also makes possible the removal of impurities contained in the sugar by centrifuging the sugar solution. Passing this hot sugar syrup through a centrifugal clarifier has revealed the accumulation of an appreciable amount of diverse foreign matter in the bowl of the centrifuge. For high quality and superior smoothness of finished product the absence of such foreign matter is essential. It likewise facilitates the complete solution of the sugar which is indispensable for the proper control of the smoothness of the finished product as explained in previous paragraphs. The obvious disadvantages of dissolving the sugar in water lie in the additional equipment and labor required and the cost of heating and evaporating the added water.

The forewarmed milk containing the added sugar is now ready to be condensed in the vacuum pan.

CHAPTER V.

THERMODYNAMICS OF CONDENSING

This chapter deals with the underlying physical factors involved in the removal of water from milk by heat. The condensing, or removal of water from milk, is accomplished by evaporation, either under atmospheric pressure, i. e., in the open air, or in a partial vacuum, i. e., under reduced pressure. While atmospheric condensing equipment is used to a considerable extent for the condensing of milk and milk by-products, the great bulk of all the condensed milk manufactured is condensed in vacuo, by the use of the vacuum pan.

ADVANTAGES OF VACUUM CONDENSING

Evaporation under reduced pressure such as is made possible by the use of the vacuum pan has several distinct advantages over condensing under atmospheric pressure. The chief of these advantages are:—economy of evaporation, rapidity of evaporation and low temperature of milk.

Effect of Condensing in Vacuo on Economy of Evaporation.—The total heat units expended when condensing in the vacuum pan at the usual temperature of about 140° F. is slightly greater than the total heat units required for evaporation under atmospheric pressure. There is no saving in total heat units due to evaporation under reduced pressure.

However, evaporation in vacuo has the distinct advantage of making possible the economical utilization of exhaust steam. Hence, where exhaust steam is available, there is opportunity for a considerable saving in fuel by its use.

The heat units involved in the evaporation of water may be conveniently classified into 4 groups. These are:—sensible heat, internal latent heat, external latent heat and thermal equivalent of energy expended by the operation of the vacuum pump. For exact heat units at different temperatures and corresponding vacua and pressures see Table 4.

Sensible Heat.—This is the heat required to raise the temperature of the liquid—milk—from any given temperature to its boiling point, or to the temperature of its vapor. To raise the temperature of one pound of water one degree Fahrenheit requires 1 B. T. U. Since the specific heat of milk is .93, it requires .93 B. T. U. to raise the temperature of one pound of milk 1° F.

In vacuum water boils at a lower temperature than 212° F. Less heat units are required to bring the liquid to the boiling point under reduced pressure than under atmospheric pressure. The difference in heat units, or the heat units saved in the vacuum pan, depends on the absolute pressure or vacuum and its corresponding boiling point. With the boiling point of water at 140° F. this difference is 212 — 140 = 72° F. Boiling at 140° F. therefore requires 72 B. T. U. less per pound of water. This multiplied by the specific heat of milk (72 × .93) is 66.96 B. T. U. To bring the milk to its vapor temperature, or the temperature at which it is usually boiling in the vacuum pan, therefore, effects a saving of 66.96 B. T. U. per pound of milk over heating the milk to the boiling point at atmospheric pressure.

Internal Latent Heat.—This is the heat required to convert the water, at its boiling point, into steam or vapor. To convert one pound of water at 212° F. into steam at the same temperature requires 898.8 B. T. U. Lowering the boiling point by a corresponding decrease in pressure below that of the atmosphere increases the number of heat units required. In a vacuum of 23.81 inches, which is equivalent to a pressure of 3 pounds and to a temperature of 141.49° F., the evaporation of one pound of water requires 947.6 B. T. U. of internal latent heat, or 48.8 B. T. U. more than at atmospheric pressure at which the corresponding boiling temperature is 212° F.

External Latent Heat.—This is the heat representing the thermal equivalent of the energy expended by the vapors in making room for themselves against the pressure of vapors and air over the boiling liquid—the milk. When evaporating under atmospheric pressure with the corresponding vapor temperature of 212° F., the air pressure over the boiling liquid is 14.7 pounds. This air pressure retards the removal of the vapors, and energy must be expended by them to overcome it. When condensing in the vacuum pan a large portion of this external heat work done by the vapors in making room for themselves against the atmosphere is eliminated.

This is made possible by the continuous removal of the air by the vacuum pump and of the vapors by the condenser and the vacuum pump. The actual saving of heat units as external latent heat accomplished in the vacuum pan is not as great as would be indicated by the difference in pressure over the milk, i. e., between atmospheric pressure (14.7 pounds) and vacuum pan pressure (about 3 pounds), because of the much greater expansion of the vapors under reduced pressure. Thus, one pound of saturated vapor at atmospheric pressure has 26.81 cubic feet, while one pound of saturated vapor at 23.8 inches vacuum (3 lbs. pressure) has 118.7 cubic feet.

Thermal Equivalent of Energy Expended by Vacuum Pump.—When milk is evaporated in the vacuum pan the vapors are condensed in the condenser and the air and the discharge of the condenser consisting of water of condensation and water used for condensing, are forced out through the vacuum pump. In discharging the air and water the pump must overcome the difference in pressure between the reduced pressure in the suction and the atmospheric pressure at the discharge. The atmospheric pressure is 14.7 pounds and the reduced pressure about 3 pounds per square inch. The pump, therefore, must overcome a pressure difference of approximately 11.7 pounds per square inch, and for every pound of water evaporated it must discharge against this pressure about 20 pounds of water plus all the air which is entering through the milk, water and leaks. The thermal equivalent of the energy thus expended by the vacuum pump is estimated approximately at 50 B. T. U. per pound of water evaporated.

In the case of evaporation under atmospheric pressure there is no pump energy expended but more external latent heat must be used by the vapors in making room for themselves against the pressure of air and vapors.

In case the pan is equipped with barometric condenser, the water column of the condenser represents the pressure. No energy need be expended because the water in this case must be discharged 34 feet below the condenser which is the approximate equivalent of the pressure difference between the vacuum and the atmosphere.

Table 4.—Properties of Saturated Steam at Different Vacua and Pressures.

(Figures calculated and assembled from G. A. Goodenough, "Properties of Steam and Ammonia," 1915.)

Absolute Pressure		Vacuum inches by Mercury Column Vacuum Gauge	Boiling Temperature of Water °F	Volume Cubic Feet per Lb.	Total Heat Units B. T. U.	Sensible Heat of Liquid B. T. U.	Latent Heat		
Inches of Mercury	Lbs. per Sq. Inch						Internal or Heat of Evaporation B. T. U.	External or Energy Equivalent B. T. U.	Total B. T. U.
0.2	0.0982	29.72	34.55	2992	1074.2	2.56	1016.3	55.4	1071.7
0.4	0.1965	29.52	52.67	1550	1082.8	20.75	1005.7	56.3	1062.0
0.6	0.2947	29.32	63.98	1056	1088.1	32.06	998.4	57.6	1056.0
0.8	0.3929	29.12	72.35	805	1091.9	40.42	993.0	58.5	1051.5
1.0	0.4912	28.92	79.06	652	1095.0	47.11	988.7	59.2	1047.9
1.2	0.589	28.72	84.64	549	1097.6	52.72	985.0	59.9	1044.9
1.4	0.688	28.52	89.54	474.3	1099.8	57.57	981.9	60.4	1042.3
1.6	0.786	28.32	93.83	418.2	1101.8	61.84	979.1	60.9	1040.0
1.8	0.884	28.12	97.67	374.3	1103.5	65.68	976.6	61.3	1037.9
2.0	0.982	27.92	101.17	338.9	1105.1	69.16	974.3	61.7	1036.0
2.036	1.	27.884	101.76	333.3	1105.4	69.76	973.9	61.7	1035.6
4.072	2.	25.848	126.10	173.6	1116.2	94.02	957.9	64.3	1022.2
6.108	3.	23.812	141.49	118.7	1122.9	109.38	947.6	65.9	1013.5
8.144	4.	21.776	152.99	90.6	1127.9	120.9	939.9	67.1	1007.0
10.180	5.	19.740	162.25	73.5	1131.7	130.1	933.6	68.0	1001.6
12.216	6.	17.704	170.07	62.0	1135.0	137.9	928.2	68.9	997.1
14.25	7.	15.67	176.85	53.7	1137.8	144.7	923.6	69.5	993.1
16.29	8.	13.63	182.87	47.35	1140.3	150.8	919.4	70.1	989.5
18.32	9.	11.60	188.28	42.41	1142.5	156.2	915.6	70.7	986.3
20.36	10.	9.56	193.21	38.43	1144.4	161.1	912.2	71.1	983.3
22.40	11.	7.52	197.75	35.16	1146.2	165.7	909.0	71.5	980.5
24.43	12.	5.49	201.96	32.41	1147.9	169.9	906.0	72.0	978.0
26.47	13.	3.45	205.88	30.07	1149.4	173.8	903.2	72.4	975.6
28.50	14.	1.42	209.56	28.06	1150.8	177.5	900.6	72.7	973.3
29.92	14.697	0.00	212.	26.81	1151.7	180.0	898.8	72.9	971.7

Summary of Comparison of Heat Units Required by Evaporation under Atmospheric Pressure and in Vacuo.—The comparative economy of condensing milk under atmospheric and reduced pressure is shown by the following figures. In this example it is assumed that the milk before condensing and heating has a temperature of 60° F. and that the evaporation in the vacuum pan is done in a vacuum of 23.81 inches and at the corresponding temperature of 141.49° F.

Table 5.—Comparison of Economy of Condensing under Atmospheric Pressure and in Vacuo

Heat required	Evaporation	
	Under atmospheric pressure	In the vacuum pan
Sensible heat	152. B.T.U.	81.4 B.T.U.
Internal latent heat	898.8 B.T.U.	947.6 B.T.U.
External latent heat	72.9 B.T.U.	65.9 B.T.U.
Total heat units (expended as heat)	1123.7 B.T.U.	1094.9 B.T.U.
Plus thermal equivalent expended by vacuum pump		50.
Total heat units expended	1123.7 B.T.U.	1144.9 B.T.U.

The above example clearly illustrates that, from the standpoint of heat units required to evaporate a given volume of water, or milk, evaporation in vacuo is of no advantage. In fact, the total heat units required to condense in vacuo is slightly greater than the total heat units necessary to condense the same quantity of water, or milk, under atmospheric pressure.

Economy Through Utilization of Exhaust Steam.—The fact that under reduced pressure milk is caused to boil at a relatively low temperature (about 140° F.) makes possible the use of low pressure or exhaust steam, without decreasing the temperature difference between milk and steam to a point that would retard heat transmission from steam to milk. This is a distinct advantage. In factories where exhaust steam is plentiful, much if not all of the condensing can be accomplished by the use of exhaust steam, thus saving fuel and augmenting economy of operation.

From the standpoint of economy of fuel consumption, therefore, the only advantage of condensing in vacuo over condensing under atmospheric pressure lies in the fact that the operation of the vacuum pan makes possible the economical utilization of exhaust steam.

Effect of Vacuum on Rapidity of Evaporation.—Evaporation of milk under reduced pressure is more rapid than under atmospheric pressure when using low temperature saturated steam.

In the condensing of milk the manufacturer is limited as to temperature of milk and temperature of heating surface because of the sensitiveness of milk toward heat. Since milk boils at about 212° F. at atmospheric pressure, rapid evaporation under atmospheric pressure would necessitate the use of high temperature superheated steam, in order to provide a temperature difference between milk and steam sufficiently great to maintain the required rapidity of heat transmission. Boiling the milk at this high temperature and exposing it to so hot a heating surface long enough (from 1 to 3 hours) to complete the condensing process, would inevitably destroy its natural character and injure its quality and marketable properties.

On the other hand, such condensing in the vacuum pan under reduced pressure, and at the usual temperature of about 140° F., and at a corresponding vacuum of approximately 24 inches, makes possible the maintenance of a large temperature difference between steam and milk even when using low-temperature saturated steam. This in turn insures rapid heat transmission and, therefore, rapid evaporation at a relatively low boiling temperature, without exposing the milk to an excessively high-temperature heating surface.

The fundamental factor that determines the rapidity of evaporation is the rapidity of heat transmission or the amount of heat transmitted by the steam to the milk per square foot of heating surface per hour. The rapidity of heat transmission in turn depends on the temperature difference between steam and milk. The greater this temperature difference, the more heat is transmitted per unit heating surface per hour and therefore the more rapid the evaporation of the water contained in the milk.

The higher the vacuum or the lower the pressure in the pan, the lower the temperature at which milk boils. Decreasing the temperature of milk under reduced pressure increases the temperature difference between steam and milk without necessitating a rise in the pressure and temperature of the steam. This wider temperature difference causes more rapid heat transmission and augments the speed of evaporation. Hence the higher the vacuum in the pan the more rapid the evaporation.

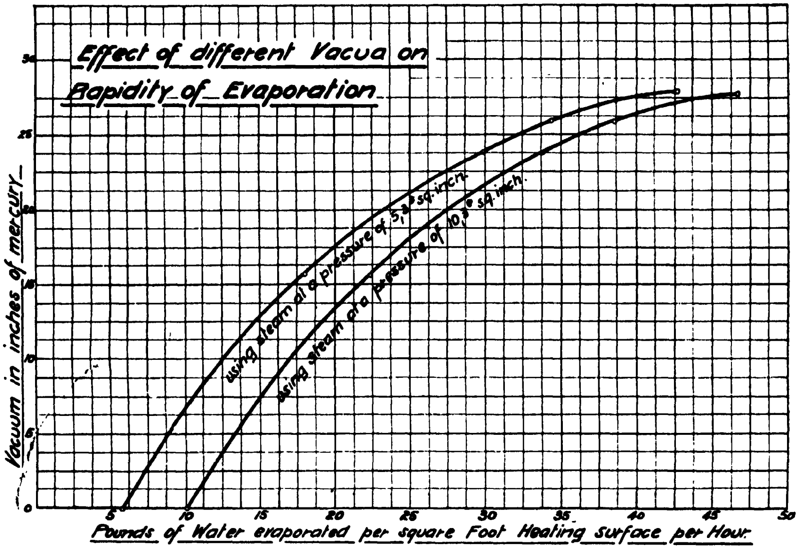


Fig. 22. Effect of heating surface on water evaporation

The amount of water evaporated per square foot heating surface per hour under atmospheric pressure and in different vacua, using 5.3 lbs. and 10.3 lbs. of saturated steam, respectively, is shown in the following calculations and also in chart Fig. 22. These calculations are based on the heat values given in Tables 4 and 10.

Pounds of Water Evaporated Per Square Foot Heating Surface per Hour

Heat transmission coefficient of copper 350 B.T.U. per sq. ft., per hour, per 1° F. temp. diff.

Evaporation at Atmospheric Pressure

(Using saturated steam at a pressure of 5.3 lbs.)

Heat of evaporation per pound of water (Total latent heat .... = 971.7 B.T.U.
Temperature of 5.3 lbs. saturated steam............ = 228° F.
Boiling point of milk under atmospheric pressure...... = 212° F.

Temperature difference between steam and milk (228-212) .... = 16° F.
Heat transmission per sq. ft. per hour 16x350......... = 5600 B.T.U.
Pounds of water evaporated per sq. ft. per hour, $\frac{5600}{971.7}$ = 5.76 lbs.

Evaporation in Vacuum Pan, Vacuum 23.81 Inches

(Using saturated steam at a pressure of 5.3 lbs.)

Heat of evaporation per pound of water............. = 1013.5 B.T.U.
Temperature of 5.3 lbs. saturated steam............. = 228 ° F.
Boiling point of milk at 23.81 inches vacuum......... = 141.49° F.

Temperature difference between steam and milk...... = 86.51° F.
Heat transmission per sq. ft. per hour 350 x 86.51..... = 30,278.5 B.T.U.
Pounds of water evaporated per sq. ft. per hour, $\frac{30,278.5}{1013.5}$ = 29.9 lbs.

Evaporation in Vacuum Pan, Vacuum 27.884 Inches

(Using saturated steam at a pressure of 5.3 lbs.)

Heat of evaporation per pound of water............. = 1035.6 B.T.U.
Temperature of 5.3 lbs. saturated steam............. = 228 ° F.
Boiling point of milk at 27.884 inches vacuum......... = 101.76° F.

Temperature difference between steam and milk....... = 126.24° F.
Heat transmission per sq. ft. per hour 126.24 x 350.... = 44,184 B.T.U.
Pounds of water evaporated per sq. ft. per hour $\frac{44,184}{1035.6}$ = 42.66 lbs.

Evaporation at Atmospheric Pressure

(Using saturated steam at a pressure of 10.3 lbs.)

Heat of evaporation per pound of water............. = 971.7 B.T.U.
Temperature of 10.3 lbs. saturated steam............. = 240.1° F.
Boiling point of milk at atmospheric pressure........ = 212° F.

Temperature difference between steam and milk...... = 28.1° F.
Heat transmission per sq. ft. per hour 28.1 x 350...... = 9835 B.T.U.
Pounds of water evaporated per sq. ft. per hour, $\frac{9835}{971.7}$ = 10.12 lbs.

Evaporation in Vacuum Pan, Vacuum 23.81 Inches

(Using saturated steam at a pressure of 10.3 lbs.)

Heat of evaporation per pound of water............ = 1013.5 B.T.U.
Temperature of 10.3 lbs. saturated steam.............. = 240.1 ° F.
Boiling point of milk at 23.81 inches vacuum.......... = 141.49° F.

Temperature difference between steam and milk...... = 98.61° F.
Heat transmission per sq. ft. per hour 98.61° F. x 350 = 3451.35 B.T.U.
Pounds of water evaporated per sq. ft. per hour, $\frac{3451.35}{1013.5}$ = 34.05 lbs.

Evaporation in Vacuum Pan, Vacuum 27.884 Inches

(Using saturated steam at a pressure of 10.3 lbs.)

Heat of evaporation per pound of water.............. = 1035.6 B.T.U.
Temperature of 10.3 lbs. saturated steam.............. = 240.1 ° F.
Boiling point of milk at 27.884 inches of vacuum...... = 101.76° F.

Temperature difference between steam and milk...... = 138.34° F.
Heat transmission per sq. ft. per hour 138.34 x 350.. = 48,419 B.T.U.
Pounds of water evaporated per sq. ft. per hour, $\frac{48,419}{1035.6}$ = 46.75 lbs.

Table 6.—Summary of Above Figures

Vacuum in pan Inches mercury column	Temperature of milk ° F.	Lbs. of water evaporated per sq. ft. heating surface per hour	
		5.3 lbs. steam pressure	10.3 lbs. steam pressure
Atmospheric pressure......	212	5.76	10.12
23.81 inch vacuum........	141.5	29.90	34.05
27.884 inch vacuum.......	101.76	42.66	46.75

The above figures show that evaporation per square foot of heating surface in vacuo is far more rapid than under atmospheric pressure, and that the higher the vacuum the greater the speed of evaporation. These figures also indicate that the rapidity of evaporation in the vacuum pan does not materially increase by increasing the pressure of the steam used in jacket and coils.

Effect of Condensing in Vacuo on Quality of Milk.—Condensing in the vacuum pan makes possible low temperature evaporation. This protects the milk against the damaging effect of high heat and preserves the quality of the milk.

As already explained under the caption "Effect of Vacuum on Rapidity of Evaporation," evaporation in commercial manufacture demands rapid heat transmission from steam to milk. Rapidity of heat transmission depends fundamentally on the temperature difference between steam and milk. The greater the temperature difference the more rapid is the transmission and utilization of the heat.

The temperature difference is determined by the temperature of the milk and the steam. Under atmospheric pressure the boiling temperature of water is about 212° F. In order to provide a temperature difference sufficiently great to make possible reasonably rapid heat transmission, it is necessary to use high-temperature, high-pressure superheated steam. Condensing milk under atmospheric pressure would, therefore, necessitate its prolonged boiling at 212° F.* and its exposure to so hot a heating surface as to impair its quality. It would change the chemical and physical properties of the milk and would cause it to assume a disagreeable cooked taste and to give it an objectionable dark color. Its quality and marketable properties would be destroyed.

Condensing milk in the vacuum pan makes possible evaporation at a relatively low temperature. At the usual vacuum maintained the milk boils at between 130 and 140° F. This low boiling temperature greatly increases the temperature difference between milk and steam. It makes possible, therefore, the use of low temperature saturated steam and protects the milk against the damaging effect to contact with a dangerously high-temperature heating surface. The natural character of the milk is preserved. The composition and properties of its constituents are not altered. Its taste, color and marketable properties remain normal and intact.

THE VACUUM GAUGE AND ITS FLUCTUATIONS

Relation of Vacuum to Pressure.—Vacuum means a complete void. In the operation of the vacuum pan such a condition does not exist. What does exist is a pressure lower than the atmospheric pressure. What is called vaccum, therefore, is not vacuum in the true sense, but it is reduced pressure below the pressure of the atmosphere, ranging from about zero to atmospheric pressure which is 14.7 lbs. per square inch at the sea level. Correctly speaking, everything above zero is pressure.

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*The boiling point of milk is slightly higher than that of water. See "Effect of Density of Milk on Reading of Vacuum Gauge."

The Absolute Pressure Gauge.—The pressure is measured by the absolute pressure gauge. The readings of this gauge are independent of the barometric pressure, or changes of level of mercury in the mercury cistern. In this gauge pressure is measured by the inches of mercury column which it sustains. The absolute pressure gauge shows the actual pressure in the pan, regardless of fluctuations in altitude or barometric conditions.

In American condenseries, however, the absolute pressure is not expressed in terms of pressure, but is expressed in terms of vacuum units. The vacuum units may be determined indirectly by means of the absolute pressure gauge, by subtracting the absolute pressure from 30 inches, which is the height of the mercury column sustained by the atmosphere at sea level. The correct height of mercury column sustained by the atmospheric pressure at the sea level, which has been accepted as standard, is 760 mm. or 29.92 inches. For simplicity and convenience of calculation the generally adopted round figure of 30 inches will be used in the discussions in succeeding paragraphs.

The Mercury Column Vacuum Gauge.—Direct readings of the vacuum are obtained by the use of the mercury column vacuum gauge, such as is in general use in American condenseries. This gauge is so designed and connected that the vacuum is measured in inches of mercury column. This gauge records the pressure difference between inside and outside of pan in inches of vacuum. Under atmospheric conditions other than the standard atmospheric pressure at the sea level these readings do not show the true or absolute vacuum in the pan, because they are not independent of altitude and other atmospheric conditions. They, therefore, must be corrected for atmospheric pressures other than 30 inches of mercury or 14.7 lbs. per square inch, as shown later in this chapter.

The pressure corresponding to 1 inch of mercury column may be conveniently expressed by the following formula:

$$1 \text{ inch mercury column} = \frac{14.7}{30} \times (30 - 29) = .49 \text{ pounds pressure.}$$

In order to find the absolute pressure in pounds per square inch, it is necessary to determine the absolute pressure in inches of mercury which is the difference between the atmospheric pres-

Table 7.—Barometric Reading and Corresponding Pressures at Different Altitudes

Barometric reading in inches of mercury	Atmospheric pressure in pounds per square inch	Altitude above sea level in feet	Barometric reading in inches of mercury	Atmospheric pressure in pounds per square inch	Altitude above sea level in feet
30.0	14.70	0	23.5	11.54	6412
29.7	14.60	264	23.0	11.30	6977
29.5	14.47	441	22.5	11.05	7554
29.2	14.35	710	22.0	10.80	8144
29.0	14.23	890	21.5	10.56	8747
28.7	14.11	1163	21.0	10.31	9366
28.5	13.98	1347	20.0	9.81	10648
28.2	13.86	1625	19.0	9.32	11994
28.0	13.74	1812	18.0	8.82	13413
27.5	13.50	2285	17.0	8.33	14914
27.0	13.26	2767	16.0	7.84	16506
26.5	13.02	3257	15.0	7.35	18201
26.0	12.77	3758	14.0	6.86	19996
25.5	12.53	4268	13.0	6.37	21891
25.0	12.27	4787	12.0	5.88	23886
24.5	12.03	5318	11.0	5.39	25981
24.0	11.78	5859			

sure expressed in inches of mercury and the pan pressure expressed in inches of vacuum, and then multiply this difference by .49.

Example: Atmospheric pressure is 30 inches mercury column, vacuum gauge reading is 25 inches mercury. What is the absolute pressure in pan?

The absolute pressure is (30 — 25) × .49 = 2.45 pounds per square inch.

Effect of Altitude on Reading of Mercury Column Vacuum Gauge.—The adopted standard for atmospheric pressure at the sea level is 760 mm. or 30 inches of mercury column. This corresponds to a pressure of 14.7 pounds per square inch.

At altitudes higher than the sea level the atmospheric pressure drops. The higher the altitude the lower the atmospheric pressure and the fewer the inches of mercury column sustained. Table 7 shows the atmospheric pressure and barometric reading in inches of mercury at altitudes ranging from the sea level to 25,981 feet above the sea level and in Table 8 may be found the altitudes of various cities in the United States.

Table 8.—Altitude in Feet of Various Cities in the United States

By Courtesy of the United States Department of Agriculture

Akron, Ohio	940
Albany, N. Y.	22
Atlanta, Ga.	1032
Baltimore, Md.	92
Birmingham, Ala.	600
Boston, Mass.	16
Buffalo, N. Y.	583
Burlington, Vt.	112
Butte, Mont.	5555
Charleston, S. C.	12
Chattanooga, Tenn.	672
Chester, Pa.	22
Chicago, Ill.	590
Cincinnati, Ohio	490
Cleveland, Ohio	582
Dayton, Ohio	740
Denver, Colo.	5183
Dallas, Tex.	430
Des Moines, Iowa	805
Detroit, Mich.	588
Duluth, Minn.	609
Houston, Tex.	46
Indianapolis, Ind.	708
Ithaca, N. Y.	411
Kansas City, Mo.	750
Knoxville, Tenn.	890
Lexington, Ky.	955
Little Rock, Ark.	264
Los Angeles, Calif.	267
Louisville, Ky.	453
Memphis, Tenn.	256
Milwaukee, Wis.	593
Minneapolis, Minn.	812
New Haven, Conn.	10
New Orleans, La.	6
New York City	54
Oklahoma City, Okla.	1197
Omaha, Neb.	1016
Philadelphia, Pa.	42
Phoenix, Ariz.	1082
Pittsburgh, Pa.	743
Providence, R. I.	11
Richmond, Va.	51
Rochester, N. Y.	510
St. Louis, Mo.	455
Salt Lake City, Utah	4238
San Francisco, Cal.	15
Santa Fe, N. M.	6952
Seattle, Wash.	10
South Bend, Ind.	717
Spokane, Wash.	1908
Tampa, Fla	15
Washington, D. C.	25
Wichita, Kan.	1294
Vicksburg, Miss.	196

According to Kent[38] the relation of altitude to atmospheric pressure per square inch is as follows:

Altitude	Pounds Pressure Per Square Inch
At sea level	14.7
¼ mile above sea level	14.02
½ mile above sea level	13.33
¾ mile above sea level	12.66

Altitude	Pounds Pressure Per Square Inch
1 mile above sea level	12.02
1¼ miles above sea level	11.42
1½ miles above sea level	10.88
2 miles above sea level	9.80

"For a rough approximation we may assume that the pressure decreases one-half pound per square inch for every 1,000 feet of ascent."

In factories located at altitudes higher than the sea level, the mercury column vacuum gauge will, therefore, show fewer inches of vacuum at a given pan temperature than at the sea level at the same temperature. This is due to the change in pressure difference between the absolute pressure in the pan and the atmospheric pressure outside. The temperatures of the milk and vapors in the pan are controlled by the absolute pressure in the pan. The absolute pressure in the pan is independent of and does not alter with fluctuations of the atmospheric pressure outside. It follows, therefore, that the pressure difference between absolute pressure in the pan and atmospheric pressure outside decreases with an increase in the altitude. Since the mercury column vacuum gauge records the vacuum in terms of inches of mercury column sustained, a decrease in pressure difference, such as is caused by lower atmospheric pressure due to higher altitude, necessarily shows fewer inches of vacuum on this gauge. The following example may suffice to illustrate this fact:

Example.—The pan is operated at a boiling temperature of say 141.5° F. At this temperature the absolute pressure in the pan is 3 lbs. per square inch. What is the mercury column vacuum gauge reading at the sea level? What is the corresponding reading at Santa Fe, New Mexico?

Answer.—At the sea level the atmospheric pressure is 14.7 lbs. The pressure difference, therefore, is $14.7 - 3 = 11.7$ lbs. This pressure difference corresponds to a vacuum gauge reading of $11.7 \times \frac{30}{14.7} = 23.8$ inches. The vacuum in the pan operated at 141.5° F. as recorded by the mercury column vacuum gauge at the sea level therefore is 23.8 inches.

Santa Fe, New Mexico, is located at an altitude of 6,952 feet as indicated in Table 8. Table 7 shows that at this altitude the atmospheric pressure is 11.54 pounds per square inch. The absolute pressure in the pan at the same temperature (141.5° F.) is 3 lbs. Hence, the pressure difference is $11.54 - 3 = 8.54$ lbs. per square inch. This pressure difference corresponds to a vacuum reading of $8.54 \times \frac{30}{14.7} = 17.43$ inches. The vacuum in the pan operated at 141.5° F., as recorded by the mercury column vacuum gauge at Santa Fe, New Mexico (altitude 6,952 feet), therefore is 17.43 inches.

The above example clearly shows that at a given temperature the number of inches of vacuum recorded by the mercury column vacuum gauge decreases as the altitude increases, although the absolute pressure and absolute vacuum in the pan remain the same at the same temperature as they are at sea level.

Effect of Air in Pan on Reading of Mercury Column Vacuum Gauge.—The relation of vacuum in inches of mercury column to absolute pressure per square inch at different boiling temperatures of water is shown in Table 4. The pressure in the pan corresponding to the vacuum indicated at any given temperature represents the sum of vapor pressure and of air pressure present. Some air is always present in the pan due to the fact that the vacuum pump is never 100 per cent efficient, and that air is continuously entering with the incoming milk, with the incoming cooling water in the condenser and through leaky joints and fittings because of the great pressure difference between the atmospheric pressure outside and the vacuum inside of the pan.

The absolute pressures shown in Table 4 for different temperatures represent the absolute vapor pressure of saturated steam at corresponding temperatures. In the practical operation of the vacuum pan it will be found that the pressure indicated in the table is always slightly lower (the vacuum recorded is slightly higher) than its equivalent shown by the recorded vapor temperature in the pan. This is so because the temperature of the vapor corresponds to the vapor pressure only and not to the gauge pressure which represents the sum of vapor pressure and air.

The above discrepancy between the absolute vapor pressure shown in Table 4, and the actual pressure shown by the vacuum gauge in terms of inches of vacuum, applies only where the temperature recorded is that of the vapor space over the milk as determined by a short-stem thermometer, the bulb of which does not reach down into the milk.

The boiling temperature of the milk (water) corresponds to the total pressure in the pan, including both vapor and air. Therefore, the temperature of the milk (water) is slightly higher than the temperature of its vapor. The gauge reading of the vacuum pan corresponds with the temperature of the boiling milk (water) and not with that of the vapors. Hence, it is necessary to record the temperature of the milk in order to make the temperature recorded and the corresponding gauge reading agree with the relation of temperature and pressure as shown in Table 4. This, therefore, requires the use of a thermometer, the bulb of which reaches into the milk.

Effect of Density of Milk on Reading of Vacuum Gauge.—The discussion and calculations in previous paragraphs relating to temperatures and pressures in the pan are based on water only. The same is true of the figures in Table 4.

When condensing milk, the actual vacuum as recorded by the mercury column vacuum gauge seldom, if ever, coincides exactly with the vacuum over water at the same temperature, as given in Table 4. The actual vacuum over milk is always slightly higher than that shown for water in the table at the same temperature.

This is due to the fact that the specific gravity of the milk

Table 9.—Boiling Points and Corresponding Vacua of Water and Sweetened Condensed Milk

Kind of liquid	Boiling point at atmospheric pressure °F.	Rise in boiling point over that of water °F.	Rise in vacuum when holding temperature the same inches	Vacuum when evaporating at a temperature of 141.5 °F. inches
Water.................	212.	0.	0.	23.81
Fresh milk.............	212.3	0.3	0.0501	23.8601
Fresh milk with sucrose added at rate of 18 lbs. sugar per 100 lbs. milk.	212.9	0.9	0.1503	23.9603
Sweetened condensed milk, spec. grav. 1.3085	217.8	5.8	0.9686	24.7786

is slightly greater than the specific gravity of water. An increase in the specific gravity raises the temperature at which the liquid boils. Milk boils at a higher temperature than water at the corresponding vacuum. The difference in specific gravity between water and fresh milk is very small (1 to 1.032) hence, at the beginning of the condensing process the actual vacuum over milk corresponds closely with the theoretical vacuum over water at the same temperature.

Each degree of Fahrenheit rise in boiling point increases the vacuum .167 inches of mercury column. The boiling point of milk under atmospheric pressure at the sea level is 212.3° F. while that of water is 212° F. Milk, therefore, boils at a slightly higher vacuum than water. The increase in vacuum is $(212.3 - 212) \times .167 = .0501$ inches.

The addition of sugar to the milk and the progressing concentration further increase the density of the milk, raise its boiling point and cause an additional rise in the inches of vacuum when evaporating at a given temperature. Thus, while at a pan temperature of 141.5° F. water boils at a vacuum of 23.81 inches, sweetened condensed milk, at the end of the condensing process, boils at the same temperature only when the vacuum has risen to 24.78 inches, as shown in Table 9. This table also shows the effect of the addition of cane sugar to the milk on boiling point and inches of vacuum at a given temperature.

Since the temperature of the vapors in the pan always corresponds to the vapor pressure or vacuum and is not affected by changes in the boiling point of the liquid, it follows that the short-stem thermometer with bulb in the vapor space will register a lower temperature than that of the milk, especially toward the end of the condensing process. Thus in the case of sweetened condensed milk, according to figures in Table 9, the temperature of the milk toward the end of the run would actually be 5.8° F. higher than that of the vapors. This emphasizes the need of using a thermometer with bulb submerged in the milk, where it is desired to determine the exact temperature of the milk.

CHAPTER VI

DESCRIPTION OF VACUUM PAN UNIT

The vacuum pan is a retort in which the milk is condensed under reduced pressure. Attached to the pan is the condenser for reducing the vapors to liquid form, and the vacuum pump for removing the condensed vapors and air. The great majority of vacuum pans used for condensing milk are made of copper. In recent years pans of chromium-nickel steel, all-nickel pans and glass enameled pans have also been introduced into the milk condensery. See also Chapter II on "Metals in Dairy Equipment."

The vacuum pans used in the commercial manufacture of condensed milk range from 3 feet to 7 feet in diameter. The vacuum pan consists of four main parts, i. e., the heating surface provided by jacket, coils, or steam chest; the waist or vapor space in which evaporation proper takes place; the dome in which the vapors collect; and the condenser where the vapors are reduced to water.

The Heating Surface.—The area, type and arrangement of heating surface play a most important part in determining the evaporative capacity of the vacuum pan. The evaporative capacity of the pan is directly proportional first, to the temperature difference between steam and milk and second, to the total area of heating surface. It is also materially influenced by the velocity with which the milk passes over the heating surface, the velocity with which the steam travels through jacket and coils, and the area of evaporating surface of the milk. All of these factors are directly or indirectly, or both, related to the size and arrangement of the heating surface.

Effect of Temperature Difference Between Steam and Milk on Evaporative Capacity of Vacuum Pan.—The evaporative capacity of the pan increases with and is directly proportional to the temperature difference between steam and milk. The higher the temperature of the steam applied to the heating surface and the lower the temperature at which the milk boils, the greater is the transmission of heat from steam to milk per square foot of heating surface per hour. See Chapter V on "Effect of Vacuum on Rapidity of Evaporation."

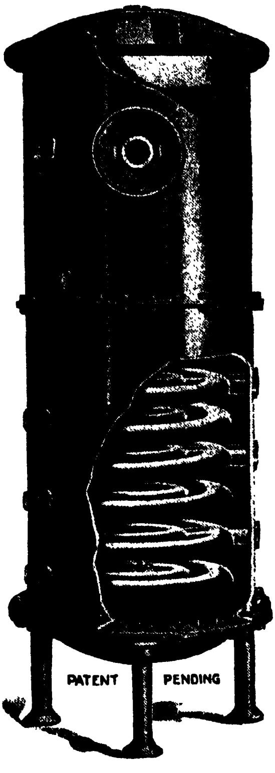

Fig. 23. The Rogers vacuum pan
Courtesy of C. E. Rogers Co.

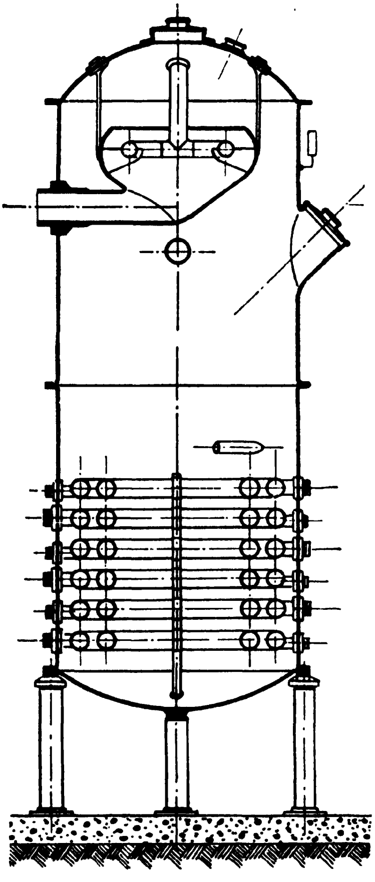

Fig. 24. The Harris vacuum pan
Courtesy of Arthur Harris & Co.

Effect of Size and Arrangement of Heating Surface on Evaporative Capacity of Pan.—The larger the heating surface, the greater the possible contact between milk and heating surface. The amount of heat transmitted to the milk per hour, other factors being the same, is proportional to the square of the heating surface. Therefore, the larger the heating area the greater is the evaporative capacity of the pan. For details see

"Effect of Condensing in Vacuo on Economy of Evaporation," Chapter V.

The heating surface is provided either by a steam jacket, or a series of steam coils, or both, or by milk tubes surrounded by a steam chest or calandria, as described later in this chapter.

The **Jacket** is at and forms the bottom of the pan. It is generally concave or dished, the curve varying in different types of pans from a depth of a few inches to the radius of the waist of the pan. The jacket is equipped with two steam inlets and one or two outlets for the condensation water. At the lowest point of the bottom there is an opening, from two to four inches in diameter, for the discharge of the condensed milk. This outlet is usually equipped with two valves and a short nipple between valves, to make possible the sampling of the condensed milk while the pan is in operation.

In some of the later pan constructions the jacket is omitted entirely, the pan terminating at its base in a single-wall bottom, either slightly concave or slightly convex, for the purpose of reinforcement to withstand the pressure difference between interior and exterior of pan. In such pans the heating surface is confined to the coils.

The **Coils** are located in the lower section of the body or waist of the pan. Most pans have two or more sets of coils with steam inlets and condensation water discharges through the wall of the pan. Since steam should be turned into the coils only when they are covered with the milk, the coils must be located below the level at which the milk is normally carried in the pan.

In pans with deeply dished bottoms or jackets, the coils are usually of the basket type, extending downward to near the bottom. In pans with shallow jacket or no jacket, the upper coils extend farther up in the waist of the pan and the level of the boiling milk is carried higher. In such pans, the danger of entrainment losses is avoided by a taller construction of the waist.

In present day pan construction the length of the coils is reduced and the number of coils is increased. Each coil is confined to only one or one-half convolution. The pan contains numerous of these short, independent coils installed one above the other with sufficient space between to permit of ready access for cleaning, and each coil has its independent steam inlet and condensate outlet. This arrangement greatly augments heat transmission and velocity of evaporation.

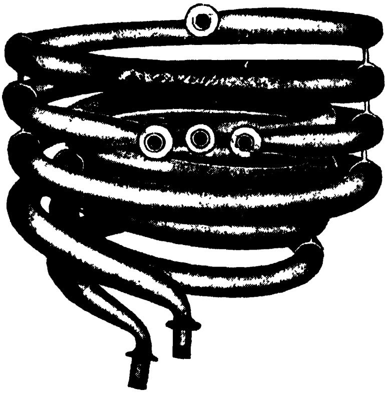

Fig. 25. Basket coil
Courtesy of Arthur Harris & Co.

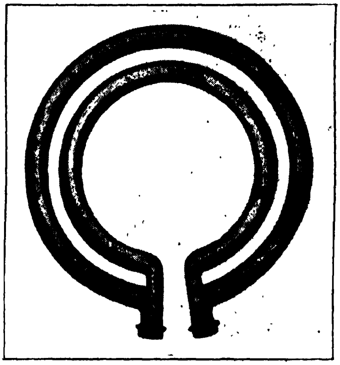

Fig. 26. Single-turn coil
Courtesy of C. E. Rogers Co.

Effect of Velocity of Circulation of Milk over Heating Surface on Evaporative Capacity of Pan.—The effectiveness of the heating surface, or its ability to transmit heat to the milk, is materially influenced by the rapidity with which the milk passes over it. The greater the velocity at which the milk circulates, the more rapid is the transmission of heat from steam to milk. According to Ser and Joule[39] this additional heat transmission resulting from the circulation of the milk is approximately proportional to the cube root of the increase of liquid (milk) flow velocity.

The reason that the milk in the pan circulates lies in the effect of successive heating and cooling on its specific gravity and buoyancy. The milk that comes in contact with the heating surface becomes hotter and therefore lighter than the remainder of the milk in the pan. The buoyancy of this heated milk forces it upward. When it reaches the vapor space it cools rapidly due to evaporation. It thereby becomes heavier, loses its buoyancy, rolls over and drops back to the bottom where it is again heated, becomes lighter and rises to the top anew, thus circulating continuously from bottom to top and return.

The velocity of circulation of the milk over the heating surface is controlled by the temperature difference between heating surface and milk, the fluidity of the milk and the arrangement of the heating surface.

The greater the temperature difference between heating surface and milk the greater the difference in specific gravity between the milk in contact with the heating surface and the remainder of the milk. Hence, the greater the buoyancy of the heated milk, and the more rapidly will it rise upward.

The more fluid the milk, the thinner will be the film that makes contact with the heating surface, the quicker will it heat and the more rapidly will it be replaced by other milk particles. During the early stages of the condensing process, when the milk is relatively thin and fluid, it passes over the heating surface with greater velocity than toward the end of the condensing

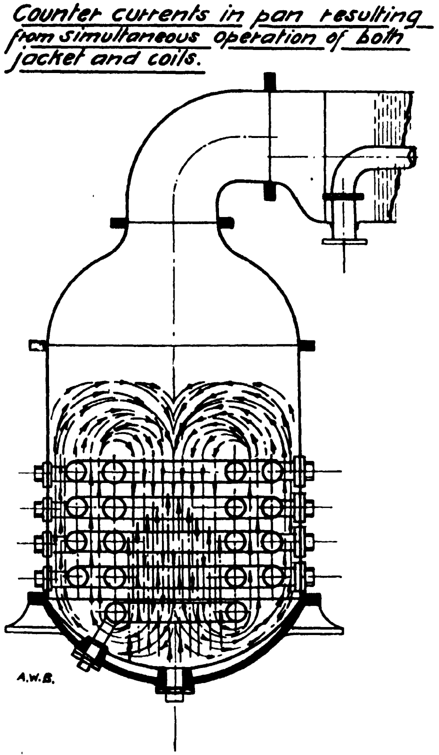
Counter currents in pan resulting from simultaneous operation of both jacket and coils.
A.W.B.

Fig. 27. Counter-currents of milk in pan with jacket and coils

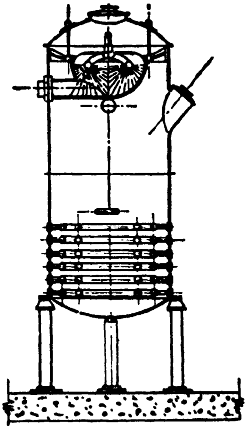

Fig. 28. Absence of counter-currents in pan with coils only

Courtesy of Arthur Harris & Co.

process when the milk is thicker and more viscous and sluggish. This is an additional reason why evaporation is much more rapid at the beginning than toward the end of the condensing process.

The velocity of the circulation of milk in the pan is very materially affected by the relative freedom from countercurrents. The velocity is greatest when the movement of the milk is in one continuous direction only, countercurrents hinder and retard the circulation. It is important, therefore, that the heating surface in the pan be so arranged as to produce maximum freedom from countercurrents.

In pans with both jacket and coils, the distribution of the heating surface is of a nature that prevents the milk from circulating in one direction only. The jacket causes the milk to "kick up" in the center, while the coils cause it to rise up near the pan wall and then roll over toward the center where its return to the bottom is retarded by milk "kicked up" by the jacket. This situation obviously is contrary to maximum velocity of circulation over the heating surface.

On the other hand, in pans which have no jacket and in which the bottom is not dished downward but is preferably convex, countercurrents are very largely avoided, the milk circulates in one direction, it arises over the coils near pan wall, rolls over the top-most coil and returns, unhindered by countercurrents resulting from the jacket, to the bottom of the pan where the heat of the coils again raises it and causes it to roll over. The circulation of the milk here is so much more rapid that the heat transmission is sufficiently accelerated to materially increase the rapidity of evaporation. The freedom from countercurrents and the speed of circulation may be further enhanced by installing in the center of the pan a tube or baffle which catches the milk as it rolls over from the top coil and carries it back to the bottom for recirculation, completely unhindered by countercurrents and not retarded by friction incident to passing downward through and meeting the resistance of the body of the milk.

Effect of Velocity of Steam in Jacket and Coils on Evaporative Capacity of Pan.—Rapidly moving steam transmits more heat than slowly moving steam, or steam at rest. The reason for this lies in the fact that the larger the number of steam molecules that strike the heating surface the more heat is transmitted from steam to heating surface. Rapidly moving steam carries more fresh molecules to the same area than slowly moving steam.

For this reason the greatest heat transmission takes place at the point at which the steam enters the jacket or coil. Heat transmission decreases, as the steam travels farther from the intake and is least at the point of exhaust. This fact is readily observed when the vacuum pan is in operation. The milk boils most violently at the point of steam intake. The ebullition diminishes at points farther removed from the steam intake and in the case of long coils it is entirely absent near the coil exhaust.

The larger the space into which the steam enters, the slower is the velocity of the steam and the lower the amount and rate of heat transmission. Long, wide coils are less effective than short and narrow coils. Heat transmission increases with the decrease in length and diameter of the coil. As the greatest amount of heat is surrendered by the steam at the entrance, the coil is most efficient at the point of entrance and least at the point of exhaust. And the smaller the diameter of the coil, the more of the steam molecules that enter the coil come in contact with its walls. Hausbrand[40] believes that, within reasonable limits, the increase of heat transmission is approximately inversely proportional to the square root of the decrease of the diameter and the shortening of the length of the coils.

Therefore, several short coils, with one turn or one-half turn only, and with large independent steam inlets and exhausts, furnish more efficient heat transmission than one or two long coils. They make for maximum evaporative capacity and economy of operation.

Furthermore, the presence in the coils of condensation water hinders the heat transmitting efficiency of the steam. The film of water coating the inside of the coil walls acts as an insulator. The more rapid and complete the removal of the condensation water, the more effective is the transmission of the steam heat. Short coils, slightly inclined, accelerate the rapid and complete removal of the water of condensation. Such coils also accelerate the removal of non-condensable gases and air, which, when present, obstruct the free passage of the steam and retard heat transmission.

The installation of numerous short coils, located one on top of the other, and with large independent steam inlets and exhausts has the further advantage that such arrangement of heating surface facilitates the condensing of small batches and makes possible the utilization of a portion of heating surface from beginning to end of the condensing process. Steam can be used in the lowest coils almost as soon as the fluid milk enters and operation of the lower coils can be continued to practically the end of the process when the milk again boils low, without danger of burning the milk on the surface of exposed coils.

The short coils with large steam intake are ideally adapted, especially to the economical utilization of exhaust steam, as they make possible the simultaneous use of large volumes of steam. The uniformity of heat distribution in all parts of the milk may be further assisted by so placing the coils as to distribute their respective steam intakes over all sides of the periphery of the pan.

The steam jacket is less efficient in heat transmission than the steam coil. In the coil the steam, upon entering, is confined to and directed through a narrow space, causing maximum contact between steam and heating surface. This is not so in the case of the jacket. Immediately upon entering the jacket the steam spreads out. It comes in direct contact with a comparatively small area of heating surface, the heating surface is on one side of the steam only and the steam spreads out and reaches the free space by the most direct route. Jackets with two or more steam inlets are more effective than those with one steam inlet only.

Effect of Evaporating Surface of Milk on Evaporative Capacity of Pan.—The larger the surface of evaporation the more rapid the evaporation. The surface of evaporation is determined by the width of the pan and the character of ebullition of the milk.

Other conditions being the same, the wider the diameter of the pan, the greater is the surface of evaporation. This fact has resulted in the general impression that evaporation is more rapid in wide, shallow pans than in narrow, deep pans of the same heating surface. This deduction is not necessarily correct for the following reasons:

In deep, narrow pans the body of the milk is deeper. In order to accommodate the desired heating surface it is necessary to install more turns of coils, one on top of the other. This provides a greater vertical range of heating surface. The milk traveling from bottom to top takes up more heat and becomes hotter and lighter. This increases its buoyancy, causing greater velocity of its upward passage. This increased velocity of circulation causes more rapid heat transmission and this in turn accelerates the speed of evaporation.

The increased speed with which the milk moves upward causes the milk to be thrown up higher into the vapor space, hence it must drop back over a longer distance. This increases the milk surface exposed to evaporation. The increased surface of evaporation in the narrow, deep pan, due to the greater vertical area of exposure of the milk spray in the vapor belt, therefore, compensates for the increase of evaporating surface caused by the greater diameter in the wide and shallow pan and the speed of evaporation is at least as great, if not somewhat greater, in the narrow pan than in the wide pan.

The Body, Waist, or Vapor Belt.—Above the jacket or bottom of the pan rises the main body, waist or vapor belt of the pan. It is here where the water contained in the boiling milk is converted into vapor. In most vacuum pans the body is cylindrical, and it should be sufficiently high to avoid the danger of entrainment losses in normal operation. The exact height must necessarily vary with the arrangement of the coils. The higher the elevation of the top coil, the taller must be the waist of the pan. Through the wall of the pan body the laterals of the steam header, located outside of the pan, connect with the coils in the pan.

Through the wall of the body of the pan also enters the milk draw pipe. This pipe connects with the hot well and through it the milk rushes into the pan. Immediately outside of the pan, the milk pipe is equipped with a valve to regulate the inflow. The size of the milk draw pipe and valve is governed by the capacity of the pan; usually being two to three inches in diameter. Inside of the pan the milk pipe should be turned down. If this provision is not made, the milk shoots straight across the pan, atomizing into a dense spray which is partly drawn over into the condenser, causing loss of milk. Or the milk inlet may be fitted into the wall of the pan in tangential direction as shown in Fig. 29. By this arrangement the milk assumes a helical motion immediately upon its entrance. This increases its velocity and enables it to surrender its superheat before it mixes with the milk already in the pan, thereby accelerating the speed of evaporation.

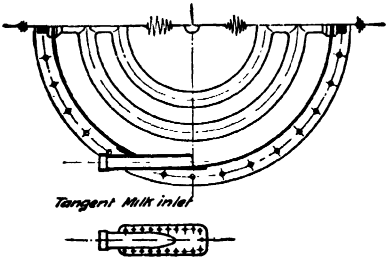

Fig. 29. Tangential milk inlet
Courtesy of Arthur Harris & Co.

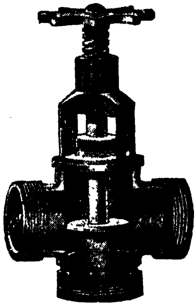

Fig. 30. Leak-proof milk valve
Courtesy of Shimp Mfg. Co.

The body of the pan also usually carries, near its lower portion, a sampling cup, or "striking cup," which facilitates the sampling and testing for density of the contents of the pan while the pan is in operation.

The pan with tall vapor belt, absence of jacket, multiple single-turn, independent coils is exemplified by the C. E. Rogers and the Arthur Harris type of vacuum pans, illustrated in Figs. 23 and 24.

The **Dome** rests on top of the body of the pan. It is equipped with a manhole, manhole cover, thermometer, vacuum gauge, spy-glasses, lights, blow-down valve or vacuum breaker, and in some of the pans of latest construction it also houses the condenser. The manhole is closed by a solid brass cover with a well-fitting, ground surface flange. The cover carries a spy-glass through which the operator watches the boiling milk in the pan. The stem of the thermometer is enclosed in a brass casing and reaches to near the bottom of the pan. Some processors prefer a short thermometer which registers the temperature of the vapors instead of that of the milk. The vacuum gauge connects with the interior of the pan, and indicates the inches of vacuum.

A mercury column may be used in the place of the vacuum gauge. In the rear of the dome there are two sight glasses. Through these the interior of the pan is illuminated by means of suitable lights.

OTHER TYPES OF VACUUM PANS

Other types of vacuum pans, the principles of construction of which lend themselves advantageously to the condensing of milk and milk products, are the Rapid Circulation Evaporator and the Recompression Evaporator.

Rapid Circulation Evaporators.—In these evaporators the steam coils and jackets are eliminated and the heating element consists of straight milk heating tubes surrounded by a steam chest. The milk level reaches part way up in the milk tubes. The steam circulating around these tubes causes the milk to boil, partly vaporize and to travel with great velocity up through the steam heated tubes. The continuous and rapid passage of the milk through the comparatively narrow milk tubes causes a large surface of the milk to come in constant contact with the heating surface, expediting heat transmission and accelerating evaporation. It also facilitates efficient utilization of exhaust steam.

The steam chest may be arranged Calandria-fashion within the lower part of the body of the vaccum pan. In this case the milk tubes are usually vertical and there is one or more large return flue or downtake for the return of the condensed milk. The milk tubes are expanded at top and bottom into horizontal tube sheets, thus forming a steam-tight chamber—the steam chest. During operation the milk is inside the tubes, but communicates with the milk in the bottom of the pan and with a certain amount of milk that covers the tube sheet at the top end of the tubes. Between these two points the milk is kept in constant vigorous circulation, passing through the tubes with great velocity.

Or, the steam chest may be located outside of the vacuum pan proper, in which case the steam chest and vapor body are preferably connected parallel to one another in a vertical position, by two pipes of large diameter. The upper pipe serves as the vapor line. The bottom pipe returns the partly condensed milk from the vapor body to the steam chest for recirculation.

The high velocity of the milk tends to keep the tubes free from coating. The vapor body is equipped with a baffle, so arranged as to reduce entrainment losses to the minimum.

In addition to low temperature concentration, speed of evaporation and minimum entrainment losses, this particular design of rapid circulation evaporator has the further advantage of easy access to heating element for cleaning. The steam chest is closed with hinged covers at top and bottom. With the covers open or removed, the milk tubes are readily cleaned by the use of a flue brush of suitable diameter.

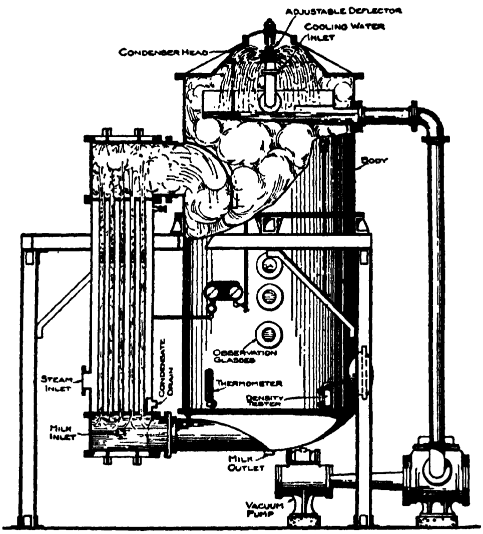

Fig. 31. Buflovak rapid circulation evaporator
Courtesy of Buffalo Foundry & Machine Co.

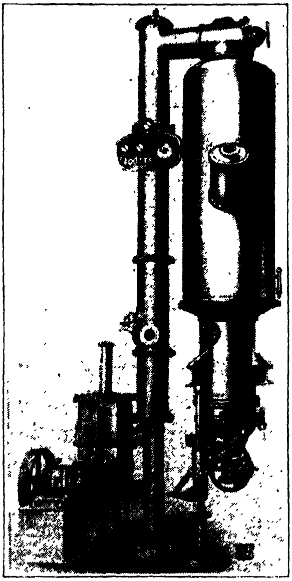

Fig. 32. Scott forced circulation evaporator
Courtesy of George Scott & Son, London

In the case of milk and milk products natural circulation of the liquid through the heating element is generally depended on; i. e., the circulation of the milk through the heating tubes is caused by the thermal difference between the steam and the milk. A typical representative of this type of evaporator is the Buflovak Rapid Circulation Evaporator, as shown in Fig. 31. In the Scott Forced Circulation Evaporator, Fig. 32, the vapor separating pan is placed above the tubular calandria and the milk is circulated down through a central nest of tubes and up through the outer tubes by the use of a low-lift, low-power centrifugal impellor.

Recompression Evaporators.—In the recompression evaportors the recompression principle involves the utilization of a part of the milk vapor generated in the evaporator. The pressure and temperature of the milk vapors is increased by injection of high pressure steam, and these compressed milk vapors are thus reused as heating steam in the evaporator in which they were generated. The utilization of this vapor by compression combines the advantages of steam and water economy of the multiple effect evaporator, low-temperature concentration, and single-effect simplicity in construction, operation and control. The recompression evaporators are preferably built on the rapid circulation evaporator principle as previously described. An outstanding example of the recompression type of evaporator is the Zaremba Recompression Evaporator shown in Fig. 33.

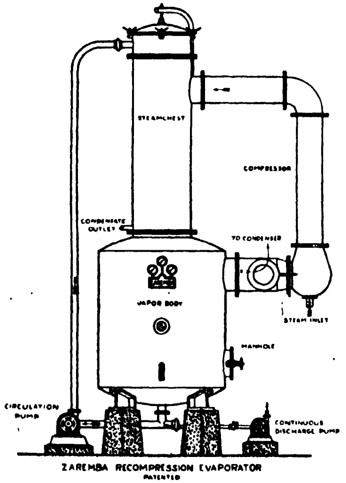

Fig. 33. Zaremba recompression evaporator
Courtesy of Zaremba Company

The Multiple-Effect Down-Flow Evaporator.—This evaporator was recently developed by the Western Condensing Co., San Francisco, California. It is the invention of David D. Peebles, the president of this company, and represents the latest development in milk evaporator design and construction. Its use in double-effect is illustrated in Fig. 33A. Each effect consists of a vertical steam chest with tubes through which the milk passes downward, a feed chamber above the upper tube sheet and a chamber at the lower end into which the tubes discharge.

The fluid milk flows into the chamber at the top of the steam chest and passes downward through the tubes to the chamber below. The tubes are heated by steam in the surrounding steam chest. The velocity with which the milk travels through the heated tubes is very high, a fact which prevents the formation of any milk coating on the tube walls, makes for maximum heat exchange, enhances rapidity of evaporation and eliminates prolonged heat exposure which is damaging to the quality of the finished product. Experience has further demonstrated that evaporated milk so manufactured possesses improved heat stability. Due to the high velocity of the milk, the heat exchange and resulting evaporation are expedited to such an extent as to greatly increase the evaporative capacity of this evaporator. A double-effect evaporator, recently installed in an evaporated milk factory in Wisconsin, is handling over 40,000 pounds of fresh milk per hour, concentrating it to the desired point by a single pass through the evaporator.

As shown under "Steam Requirements for Condensing Milk," in chapter VII, the multiple-effect unit, consisting of old style vacuum pans with steam coils, is not well suited for the evaporation of milk because the relatively high pan-operating temperature of the first effect jeopardizes the quality of the milk. In the multiple-effect down-flow type of evaporator, on the other hand, the short heat exposure eliminates this danger of heat damage. Since evaporation in succeeding effects is accomplished by utilization of the heat supplied by the milk vapors from the previous effects, evaporation by this system makes possible maximum fuel economy, the fuel requirements for evaporation being reduced in the case of the double effect by approximately 50%.

The outstanding advantages of this evaporator are rapidity of evaporation which makes for increased evaporative capacity and low initial cost of equipment as based on the volume of milk which it is capable of evaporating per hour; short exposure of the milk to heat insuring high quality of finished product; economy of operation because of low fuel requirements and of shorter

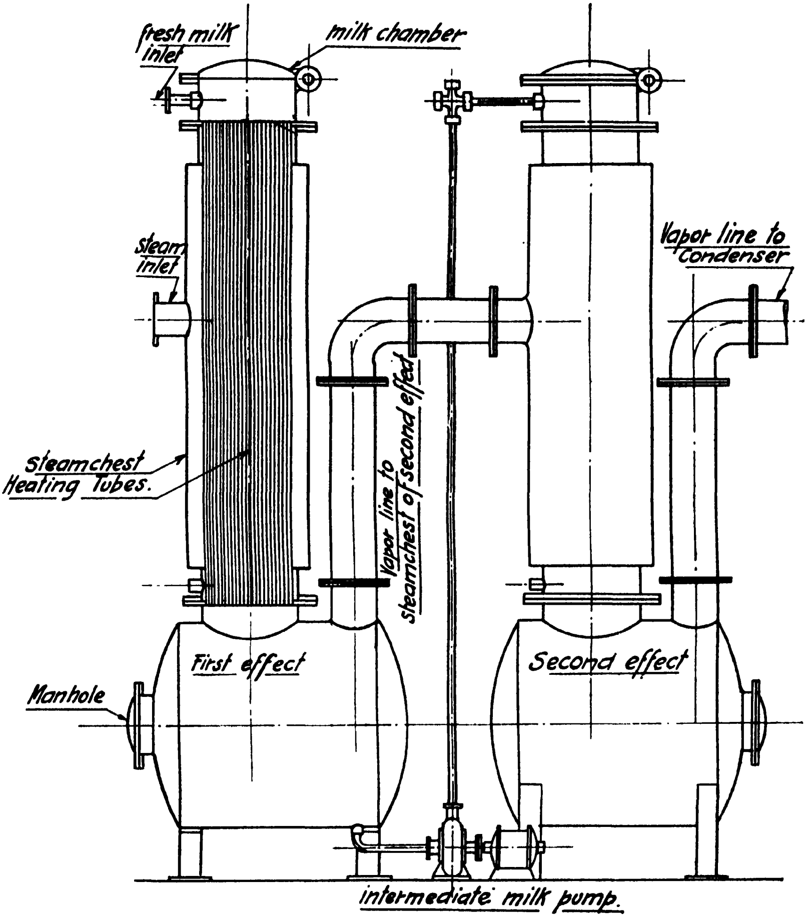

Fig. 33A. Double-effect down-flow evaporator

operating time, ease of cleaning because the high velocity of the milk eliminates milk deposits on tube walls and keeps them brightly polished, reducing the labor of cleaning to the minimum and facilitating the work of keeping the equipment in proper sanitary condition.

THE CONDENSER

Purpose of the Condenser.—The condenser is that portion of the equipment essential for evaporation under reduced pressure, which reduces the vapors rising from the boiling milk in the pan, to water. The condensing of the vapors is necessary in order to enable the vacuum pump to discharge them as fast as they are generated and thereby make possible the maintenance of a high vacuum. The condenser, therefore, supplements the function of the vacuum pump. The condensing of the vapors is accomplished by removing from them the heat of vaporization. This is done by bringing the vapors in contact with cold surfaces or by passing the vapors through a spray of cold water. The first method requires the use of surface condensers, the second method has to do with jet or spray condensers.

The **Surface Condenser** usually consists of a cylinder filled with tubes mounted on a receiver. The condensing water circulates outside of the tubes and the vapors pass through the tubes. As they come in contact with the water-cooled walls of the tubes they are chilled and condense and the water of condensation flows to the receiver. The receiver is usually equipped with suitable valves to facilitate the removal of the water without interfering with or retarding the operation of the pan.

The chief advantage of the surface condenser lies in that it keeps the water of condensation separate from the water used for condensing. This makes possible the accurate determination of the amount of water evaporated and the utilization of this water without admixture of the cooling water. The surface condenser is of small relative capacity and does not utilize the cooling water as economically as other condenser systems. Where large quantities of vapors are to be handled and they have no commercial value, as is the case in the milk condensery, the surface condenser is not well suited; in fact, it is not used in the manufacture of condensed milk.

The **Jet or Spray Condensers** used are of two general types, namely, the barometric jet condenser and the wet vacuum spray condenser. In both types the vapors are condensed by passing through a spray of cold water and the water of condensation and cooling water are discharged together.

The **Barometric Jet Condenser** connects with and discharges its water into a tight cistern in the ground. The condenser is so placed that its water outlet is located about 35 feet above the water level of the cistern in which the discharge pipe of the condenser terminates. The height of the condenser depends on the altitude or barometric pressure of the location of the factory. The lower the altitude and, therefore, the greater the atmospheric pressure, the higher must the condenser be placed above the cistern. At sea level, the atmospheric pressure sustains a water column approximately 34 feet high.

The water column seals the vacuum and permits the water discharged from the condenser to escape automatically. It is customary to build the cistern of a capacity about one-third larger than the capacity of the entire length of the discharge pipe. The cistern is equipped with a large overflow. When the pan is in operation the level of the water column remains constant and the excess water overflows from the cistern. As the barometric condenser does not discharge its water through the vacuum pump its use necessitates the installation of a dry vacuum pump for the removal of the air and non-condensable gases.

In this case the vacuum pump connects with the top of the condenser. This is an advantage because it provides very effective discharge of the air and non-condensable gases. The temperature of the air at this point is lowest due to the fact that it has been in direct and intimate contact with the cooling water.

On the other hand, the use of the barometric condenser necessitates the installation of pan and condenser at a great elevation in order to provide the necessary drainage for the overflow of the cistern. This arrangement is not always practicable under prevailing factory conditions.

The Wet-Vacuum Spray Condenser is the type of condenser most commonly used in the milk condensing factory. It differs from the barometric condenser largely in that it dispenses with the water column and cistern and discharges all the water with the air and non-condensable gases through the vacuum pump. In this case the vacuum pump seals the vacuum of the condensing system.

Types of Jet and Spray Condensers.—The jet or spray condenser consists of a large metal cylinder, either horizontal or vertical and equipped with spray pipe, spray jet or spray plate. The interior arrangement varies somewhat with different makes.

The maximum efficiency of the condenser is reached by such construction as will provide maximum water surface and longest possible contact between water and vapors. This gives maximum heat exchange and most economical utilization of the water. See also "Counter-Current Spray Condensers."

The velocity of the vapor to be condensed in the condenser decreases from its entrance to zero at the point of the water discharge. Because of this fact, the diameter of the condenser cylinder need not be larger than the vapor tube connecting with the pan, provided that the vapor tube is of adequate size, and that the condenser is properly designed.

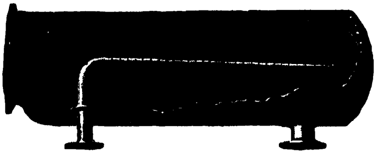

Fig. 34. Horizontal outside spray condenser

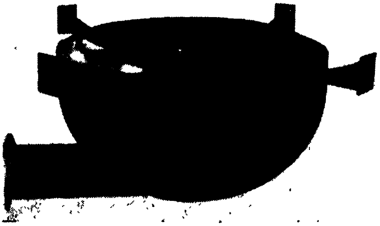

Fig. 35. Circular inside spray condenser

Courtesy of Arthur Harris & Co.

The horizontal spray condenser is usually equipped with a perforated spray pipe, placed lengthwise in the cylinder. The water supply connects with the end of the spray pipe nearest the pan and the discharge water leaves the cylinder at the opposite end. For maximum effect the spray pipe should be located near the top side of the cylinder. This accelerates the force with which the spray, that issues from perforations on the upper side of the spray pipe, strikes the top of the cylinder and assists in atomizing the water further, thereby increasing its total area of contact with the vapors. The horizontal spray condenser, as shown in Fig. 34, is the type of condenser most commonly used in milk condensing factories. In the vertical spray condenser the condenser cylinder is in upright position, located either at the side or on top of the pan. Its water intake is usually at the top and the discharge water and air leave the condenser at the bottom, while the vapors from the pan enter the condenser through the side wall near the top.

Counter-Current Spray Condensers.—The vertical condenser may also be of the counter-current type, as shown in Fig. 38,

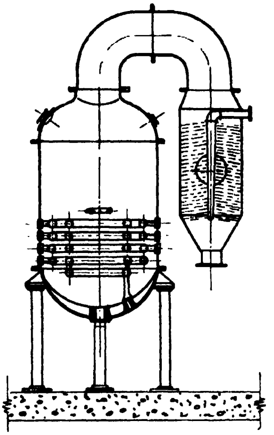

Fig. 36. Vertical down-spray condenser
Courtesy of Arthur Harris & Co.

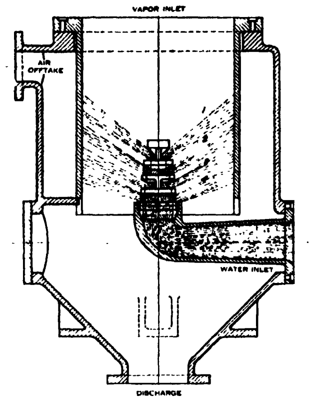

Fig. 37. Parallel-flow condenser
Courtesy of Elliott Company

and exemplified by the Byer and Elliott Condensers. In the counter-current principle the water enters at the top while the vapors enter in the side near the bottom and pass upward in counter-current to the water spray or veil; and the uncondensable gases escape at the top, being drawn out by a dry vacuum pump or an ejector.

This condenser is of considerable height and in the place of the water spray pipe or jet, the interior arrangement consists of a series of shelves, offsets or other means to cause the water to form a series of cataracts. The vapors thus pass through a succession of spray and veil of water and the condensed vapors pass off downward with the cooling water. This condenser usually, though not always, terminates at its bottom in a barometric tube, or the water is removed by a centrifugal pump.

The use of the counter-current condenser is most advantageous in localities (in the south) where the available water supply is warm, or is limited in volume, or is polluted with foreign matter. It has the advantage of maximum area of contact between vapor and cooling water. It therefore makes possible highly efficient utilization of the water, the temperature of the condenser exhaust being within a few degrees (about 2° F.) of the temperature of the vapors, thus permitting of the use of relatively high temperature water, without interfering with the

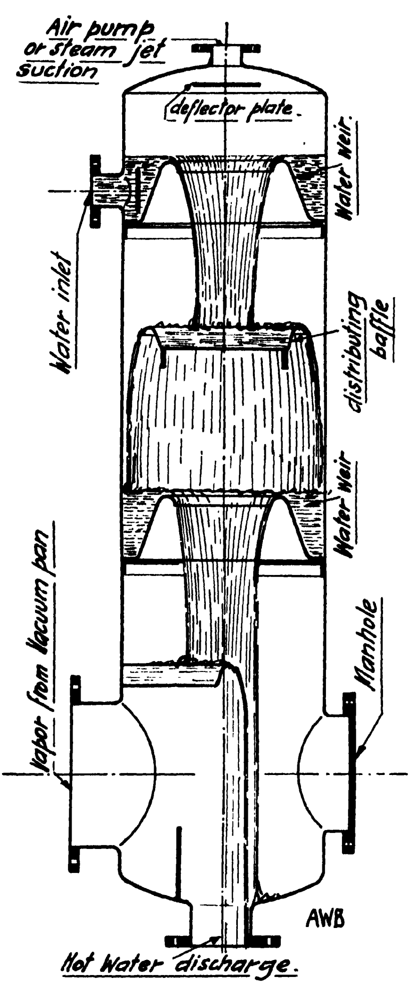

Fig. 38. The counter-current spray condenser
Showing cataract principle

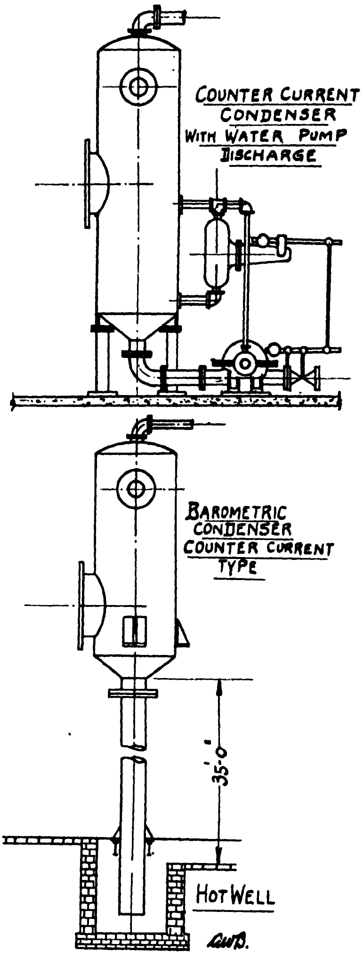
COUNTER CURRENT CONDENSER WITH WATER PUMP DISCHARGE
BAROMETRIC CONDENSER COUNTER CURRENT TYPE
35'-0
HOT WELL
AWB.

Fig. 39. Counter-current spray condensers
Top—With connections for centrifugal pump and steam ejector
Bottom—With barometric column

proper functioning of the vacuum pan. For the same reason it makes possible the re-use of the air-cooled water, thereby economizing the water supply. It expels the uncondensable gases and facilitates maintenance of a high vacuum. Because there are no small spray holes that readily clog, it permits of the use of water polluted with diverse foreign matter.

In localities where there is a plentiful supply of clean, cool water, however, the counter-current condenser is of no particular advantage and has the added drawback of greater initial expense. Its disadvantages are that it requires a large, tall condenser shell, a high vapor line, an air pump or steam ejector at the top and a barometric column or centrifugal pump at the bottom. It takes up much space, and its dimensions and internal construction limit its accessibility for cleaning and jeopardize its sanitary condition.

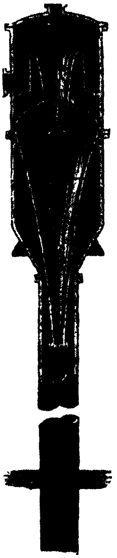

Fig. 40. Byer counter-current spray condenser
Courtesy of Byer Engineering Associates

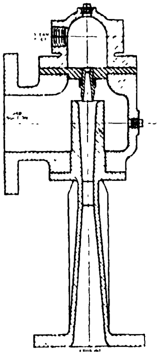

Fig. 41. Single-stage ejector

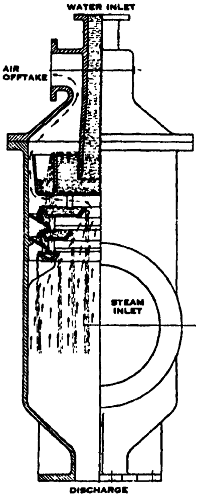

Fig. 42. Counter-current tray type condenser

Courtesy of Elliott Company

Condenser Installed Inside of Vacuum Pan.—The latest improved type of ordinary spray condenser is that located inside of the vacuum pan in the upper part of the vapor belt or immediately below the arched top as shown in Figure 23. The condenser here consists of a copper trough, U-shape in cross section, and extending to opposite sides of the pan wall through the center of the pan. The condenser trough is made of a double wall of copper with cork board insulation in between, so as to prevent the vapors from condensing on the under side of the trough and causing the condensation water to drop back into the milk.

One end of the condenser trough connects through the pan wall with the suction pipe of the vacuum pump, discharging the water from the condenser. The cooling water enters through the center of the top of the pan into a closed water distributing trough with slightly arched, perforated bottom that forms the spray. This distributing trough is located directly over the condenser trough and runs parallel with it. The perforations in the bottom of the distributing trough discharge the water spray into the condenser trough. The milk vapors in the pan are drawn through the water spray into the condenser trough from both sides by the suction of the vacuum pump. As they pass through the spray they are condensed. This type of internal condenser is used in the Rogers pan.

Factors that Influence the Efficiency of the Condenser.—The temperature and amount of available cooling water being the same, the efficiency of the condenser is chiefly influenced by its location, the surface of the water spray, the duration of exposure of the water to the vapors, and the promptness of removal of the discharge water and air.

Effect of Location of Condenser on its Efficiency.—The condenser located inside of the pan is more efficient than the condenser located outside of the pan. When the pan is in operation the point of highest vacuum lies between condenser and vacuum pump. The point of lowest vacuum is in the pan. Since the evaporative capacity of the heating surface increases with an increase in vacuum, the condenser located inside of the pan makes for maximum evaporative capacity.

When the condenser is located outside of the pan the vapors in the pan must pass through constricted channels from pan to condenser. This causes friction and this in turn lowers the vacuum and raises the temperature in the pan, and decreases the rapidity of evaporation. The smaller the diameter of the vapor tube and the greater the distance between pan and condenser, the greater the friction and the lower the vacuum in the pan.

In the case of the condenser located outside of the pan the vapors must pass through several successively constricted sections. The first section is the pan itself. Here the diameter is full size. The second section is the pan dome in which the vapors collect in a taperingly reduced space. The third section is the goose-neck or vapor tube with still smaller diameter. The speed with which the vapors travel through the constricted passages increases with the square of the decrease of the diameter, and the friction thus encountered is proportional to the fifth power (100,000 times) of the traveling speed. This friction of the vapors increases also with the length of passage and is proportional to the increase in lineal length.

The increased speed of the vapors in the case of the condenser located outside of the pan has the further objection that it augments the danger of milk spray being carried over into the condenser with the vapors thereby tending to cause excessive entrainment losses. Furthermore, in order to minimize these objections it is necessary to install large and expensive vapor tubes and connections between pan and condenser, making the initial cost of the condensing plant unnecessarily high.

And again, where the condenser is located outside of the pan the vapors strike the spray of cooling water in the condenser on one side or at one end only. The area of contact between incoming vapors and water spray is relatively small, hence large volumes of water are required to condense the vapors, the temperature of the discharge water is low and the difference in temperature between vapors in pan and discharge water from condenser is large. This means that the efficiency of water utilization is low, since the smaller the difference in temperature between vapors and discharge water, the more complete and therefore the more economical the utilization of the water. And economy of cooling water is a big factor in the condensery.

These disadvantages are part and parcel of all ordinary jet or spray condensers located outside of the pan. They do not apply, however, to the counter-current spray condenser. Most of these objections may be largely or wholly eliminated where the condenser is installed inside of the pan. Such installation has the following distinct advantages:

The vapors are condensed in the pan itself, hence the point of highest vacuum is located in the pan. This makes possible maximum evaporative capacity of heating surface, minimum temperature of milk and high speed of evaporation.

The vapors are condensed in the first section of the system, which is the pan itself. There is no need of drawing the bulky vapors through constricted sections in order to remove them to the condenser. Only the condensed vapors, in the form of water of condensation, the cooling water and the air must be discharged from the pan and these occupy far less space. The friction caused by the passing of the vapors from pan to condenser is eliminated. The velocity of the vapors is, therefore, greatly reduced and the danger of milk spray being carried over into the condenser is minimized and entrainment losses are avoided.

The vapors are drawn through the spray of cooling water on both sides of the condenser trough. They, therefore, con in immediate contact with a large surface of the water spra thereby making possible efficient utilization and economy (cooling water. Expensive and cumbersome goose-necks an vapor tubes are eliminated and the number of joints that invit air leaks is diminished. being the

Figure 35 shows an inside condenser of circulafluenced by signed by Baumann.[41] In this case the condenser on of excircular bowl with cone-shaped bottom and with the of rein the center of the condenser trough bottom. The spray rangement consists of a circular pipe with perforations covering the entire lower half of its periphery. The natural rise of the vapors is greatest near the walls of the pan because of the rapid upward circulation of the milk that is heated by the coils. The upward journey of the vapors is assisted by the greater vacuum in the condenser. Since the discharge of the condenser is in the center of its bottom, the suction is equally distributed over all sides of the circular condenser bowl. The vapors are drawn over its rim through the spray of cooling water on all sides. They strike the largest possible surface of spray, are condensed rapidly and utilize the cooling water with maximum efficiency and economy.

Effect of Surface of Water Spray on Efficiency of Condenser.—The efficiency of the condenser increases as the surface of the water spray that is exposed to the vapors increases. The surface of the spray depends primarily on its fineness. Given a sufficient amount of cooling water to condense all the vapors generated in the pan, the finer the spray the larger the surface of contact between spray and vapors, the more rapid the condensation and the more complete the utilization of the water.

In spray condensers other than the counter-current type, the fineness of the water spray is determined primarily by the diameter of the perforations in the spray pipe or spray plate. These perforations should have a diameter of about one-tenth of an inch. It also depends on the arrangement of the condenser and the force with which the water enters. Where the spray perforations are so arranged that the spray strikes the walls of the condenser, the water drops are broken up into droplets and smaller units and a portion of the water is reduced to a fine mist. The greater the force with which the spray issues forth, the more intense is its impact with the condenser walls and the finer the division of the drops. The force of the spray is controlled by the pressure difference between the atmospheric pressure outside and the vacuum inside of the pan, and it is further influenced by the elevation of the water supply tank. If the water supply tank is located at the same level as the condenser, the force of the water is equal to the full pressure difference between interior and exterior of pan. With the water supply at a level lower than the elevation of the condenser the force or velocity of the water decreases. When the water supply is located above the elevation of the condenser the force or velocity of the water increases. This decrease or increase of the force with which the cooling water enters the condenser is proportional to the square of the number of feet of elevation of the water supply below or above the elevation of the condenser, respectively.

Effect of Duration of Exposure of Water Spray on Efficiency of Condenser.—The longer the spray of cooling water is exposed to the vapors the more heat will it take up and the greater the efficiency of the condenser. Duration of exposure is an important factor, especially in condensers producing a relatively coarse spray and where the water supply is limited. With such a spray the fall of the water drops in the vertical condenser of usual height (a condenser about 3 feet high) is not great enough to permit the cooling water to warm up sufficiently.

The efficiency here may be improved by prolonging the exposure of the spray to the vapors. This is made possible by the use of the Counter-Current condenser as explained and illustrated earlier in this chapter.

Effect of Delayed Removal of Discharge Water on Efficiency

of Condenser.—Delayed removal of the warm water collecting at the discharge of the condenser causes revaporization and depreciates the efficiency of the condenser.

At the point of discharge the pressure in the condenser is lowest and the vacuum highest. The vapors entering the condenser are, therefore, condensed at a point of relatively lower vacuum and the water drops down to a point of higher vacuum (near discharge), where the corresponding temperature of vaporization is lower. Hence there is a constant tendency for the discharge water to revaporize. This tendency is greater, the higher the temperature of the discharge water, the larger the area of discharge water exposed and the longer it stays in the condenser.

For these reasons it is important to have the water outlet of the condenser and the vacuum pump of such size as to remove the discharge water as fast as it collects. In order to further facilitate this and reduce the surface of the discharge water in the condenser to the minimum it is preferable to have the condenser terminate at its bottom, or water discharge end, in a cone-shaped construction.

Amount of Water Required in the Condenser.—The amount of water required in the condenser is determined by the temperature of the water supply, the temperature of the condenser discharge and the temperature at which the milk is condensed in the pan.

Obviously, the colder the available water supply, the higher the temperature of the discharge water from the condenser and the higher the temperature in the pan, the less water is needed to condense a given amount of vapor.

The greater the difference in temperature between the water supply to and the discharge from the condenser the more economical is the utilization of the water. Also the smaller the difference in temperature between the pan and the water discharged from the condenser the less water is required. (See also Counter-Current Condenser.)

The amount of water required to condense one pound of vapor (or the vapor equivalent to one pound of water contained in the milk) may be readily calculated as shown by the following example:

Example.—Temperature of water supply is 60° F. Temperature of water discharged from condenser is 120° F. Temperature in pan is 141.5° F. How much water is required in the condenser to condense the vapors of one pound of water evaporated from the milk in the pan?

Answer.—To raise the temperature of one pound of water from 32° F. to 212° F. requires 1 B.T.U. for each degree Fahrenheit. 1 lb. of water at 120° F. therefore contains $120 - 32 = 88$ B.T.U. (For relation of temperature to B.T.U. see Table 4.)

The total heat units contained in 1 lb. of water vapor at 141.5° F. is 1122.9 B.T.U. Hence the heat units that must be removed from one pound of vapor at 141.5° F. in order to condense the vapor and cool the resulting water to 120° F. is:

$1122.9 - 88 = 1034.9$ B.T.U.

Pounds of cooling water at 60° F. required to remove 1034.9 B.T.U. is $\frac{1034.9}{(120-60)} = 17.25$ lbs. of water.

It takes 17.25 lbs. of cooling water at 60° F. to condense the vapors of one pound of water contained in the milk. The total amount of water discharged from the condenser is equal to the sum of the cooling water and the water of condensation, or in this case, $17.25 + 1 = 18.25$ lbs. water discharged from condenser per pound of water evaporated.

Maintaining the same steam pressure in jacket and coils, a decrease in temperature of the milk in the pan increases the rapidity of evaporation because it increases the temperature difference between milk and steam and this in turn accelerates heat transmission. With the steam pressure the same, the only means to lower the pan temperature lies in the use of larger quantities of water in the condenser. Using more water in the condenser, other conditions remaining the same, condenses the water vapors faster. This in turn means less pressure or a higher vacuum in the pan, which causes the milk to boil at a lower temperature.

As the volume of water supply to the condenser is increased, the temperature of the water leaving the condenser drops. This means a decrease in the heat taken up per pound of water used. Hence the utilization of the water is less efficient, it takes more water to condense a batch.

The increase in the volume of water lowers the temperature of the water from the condenser to a greater extent than it decreases the temperature of the milk in the pan. The range between condenser water temperature and pan temperature, therefore, widens.

Since there must always be a certain pressure difference between pan and condenser in order to force the vapors over into the condenser, there is a limit to the volume of water that will reduce the temperature in the pan. Also, when the volume of cooling water exceeds that necessary to condense the volume of vapors generated in the pan, the rapidity of evaporation is no longer increased and there is useless waste of water.

Condensing at high pan temperature, such as 150° F. and above, tends to economize the water supply but the rapidity of evaporation is relatively low. Condensing at low pan temperature, such as 130° F. and below, increases the rapidity of evaporation, but the water consumption is comparatively high. These statements assume the use of the same steam pressure for all conditions.

From the standpoint of preserving the natural character of the chemical and physical properties of the milk, the pan should be operated at the lowest temperature consistent with maximum rapidity of evaporation and economic utilization of water supply.

Experience in milk condensing has demonstrated that under average conditions of operation a pan temperature of 135 to 140° F. and a range of about 15 to 25° F. between pan temperature and temperature of discharge water from condenser furnish a satisfactory relation of rapidity of evaporation to economy of water consumption. This temperature is also sufficiently low to avoid noticeable objectionable changes in the properties of the ingredients of milk, and to prevent the development of a disagreeable cooked flavor and dark color. As explained earlier in this chapter, the counter-current condenser is capable of reducing the temperature difference between pan temperature and condenser water discharge to 2° F., consistent with high vacuum and low temperature of milk.

Care of Condenser.—The efficient functioning of the condenser demands that it be in proper operating condition. The perforations in the spray pipe or spray plate must be kept free from obstructions. If the water supply contains much organic matter there is a tendency for the spray equipment to become coated with slimy material, causing the clogging of some of the perforations. This is apt to be the case where the water comes from a creek, lake or pond, if not filtered, and where the condenser does not receive regular attention. In this condition the condenser cannot function properly. The spray is irregular and incomplete. The water is not utilized economically and pan operation may become difficult. The presence of foreign matter in the water, however, does not interfere with the proper functioning of the counter-current condenser.

The condenser should, therefore, be cleaned often enough to keep the spray clear of obstructions. Regular cleaning of all parts of the condenser is necessary also in order to keep it in sanitary condition. Not only the impurities in the water but also remnants of milk that may splash over into the condenser will cause a foul condition unless removed reasonably promptly. One or more peep holes, suitably placed and manholes with covers, properly located, will facilitate inspection and access to all parts. In the absence of such facilities access to the interior of the condenser is seldom sufficiently convenient to insure frequent inspection and thorough cleaning by the average operator.

THE MILK TRAP

The Milk Trap, Catch-All, or Expansion Tank is a small receptacle frequently installed between the dome and the condenser in the case of installations with the condenser located outside of the pan. Its purpose is to collect and reclaim any milk that may be carried over from the pan, so as to prevent its loss by allowing its escape through the condenser.

With the proper arrangement of milk intake and coils, adequate height of the vapor body and proper size of vapor connection to condenser, there is not much danger of heavy entrainment losses, provided that the milk is kept at a reasonable level in the pan. Under these conditions the milk trap is of no particular advantage.

If, however, the pan is of such construction as to invite the splashing of milk over into the condenser and especially if the batches of milk are of such size as to overtax the operating capacity of the pan, the entrainment loss may be very considerable, as indicated by the foaminess and milky color of the water that passes through the vacuum pump. In such cases the mechanical loss of milk of an average size batch may amount to several hundred pounds of fluid milk. Under these conditions the use of a milk trap is of advantage.

The milk trap is usually so installed that the vapors enter the trap near its top and strike the opposite side. This causes the milk particles to drop to the bottom of the trap while the vapors proper are drawn over into the condenser. The entrained milk automatically flows back into the pan from the bottom of the trap.

Some milk traps are equipped with a series of baffles, which materially assist in the efficient reclaiming of entrained milk. These baffles may be attached to and suspended from the underside of the manhole cover to facilitate their removal for cleaning after the day's run,

The milk trap is only a remedy and not a preventative. The proper construction and operation of the pan make it unnecessary. Usually an extension of the height of the vapor body is all that is necessary to prevent chronically excessive entrainment losses. Moreover, with the condenser located inside of the pan, the need of the milk trap is eliminated, as the vapors there need not be forced through constricted vapor tubes that increase the vapor velocity and cause entrainment losses.

The milk trap is an additional accessory to keep clean and its tendency is to decrease the vacuum in the pan because of added friction upon the vapors, especially in the case of baffles. Unless all parts of its interior are readily accessible and are kept clean at all times, the milk trap may become a serious source of contamination and a menace to the quality of the finished product. The sanitary condition and ease of sterilization may be improved by equipping the milk trap with steam connections.

THE VACUUM PUMP

There are three types of vacuum pumps, namely, water or steam eductors, or exhausters, rotary vacuum pumps and piston vacuum pumps. The first two types have not been found suitable for milk condensing purposes. The piston vacuum pump is practically universally used in the condensery.

Of the piston pumps there are two classes, namely, the dry vacuum and the wet vacuum pump. The chief difference here is that in the dry vacuum pump the water discharged from the condenser does not pass through the pump, while the operation of the wet vacuum pump requires the discharge water to flow through the pump.

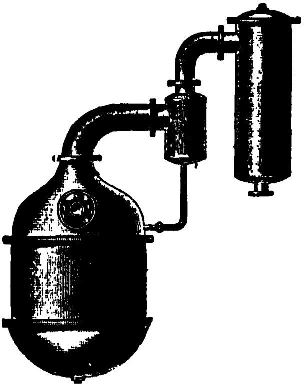

Fig. 43. Milk trap

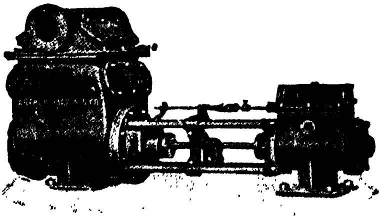

Fig. 44. Vacuum pump

Courtesy of Arthur Harris & Co.

Where the pan is equipped with a surface condenser or with a barometric condenser, the dry vacuum pump must be used. In these systems of condensing, the cooling water and the condensation water are discharged without flowing through the pump. The dry vacuum pump permits of a higher piston speed than the wet vacuum pump in which the water must be displaced with each piston stroke. Since the great majority of condenseries operate pans with the wet vacuum spray condenser, the wet vacuum pump is the type found in most condenseries.

The vacuum pump is either direct steam-driven, or it is belt driven, or it is operated by direct motor attachment, or it is of the crank and fly wheel type. The direct steam-driven pump is the least expensive to install and takes up the least space but draws heavily on the steam supply. It is used to advantage where the exhaust steam is utilized in the jacket and coils of the pan. The chief disadvantage of the direct steam-driven, single piston pump lies in the irregularity of its functioning, being subject to variations of boiler pressure. The double piston pump with fly wheel, the belt-drive and the motor-drive pumps are under most power supply conditions more economical of operation and their uniformity of action is more dependable, but their initial cost is much greater and they take up far more space.

The proper size of the vacuum pump is governed by the size of the pan and directions for the same are furnished by the manufacturer of vacuum pans.

The vacuum pump should be installed as near the pan as possible and practicable, in order that the full benefit of the vacuum may be realized. The connections must be of the size directed by the manufacturer and the suction pipe should be as short and with as few and easy bends as possible so as to eliminate excessive friction. The grade of the suction pipe should be uniform in order to avoid air pockets.

CHAPTER VII

STEAM REQUIREMENTS FOR CONDENSING MILK

Definition of Steam.—Steam may be either what is known as saturated, wet, or superheated, according to its relation of temperature to pressure and presence or absence of free moisture.

Saturated Steam.—Steam as it is generated in the boiler is called saturated steam. All steam tables are assembled, and calculations are determined on the basis of saturated steam. Each given temperature of saturated steam has its definite pressure and each given pressure of saturated steam has its definite temperature. After this relation of temperature to pressure is destroyed, we have no longer saturated steam. Saturated steam is also called dry steam,—that is, it contains no free moisture.

Wet Steam.—When steam contains free moisture in the form of a mist or spray, it is called wet steam. Wet steam has, however, the same temperature at any given pressure as saturated steam at the same pressure. Most of the saturated steam used is wet steam, because more or less spray is carried over from the boiler and also because the steam conduits are seldom, if ever, sufficiently insulated to completely prevent condensation. There is practically always some condensation in the pipes due to loss of heat by radiation.

In order to compensate for such condensation in the steam lines, large installations are frequently equipped with a superheating device at the boiler, thus supplying dry, saturated steam at the place where used.

Wet steam may also be found in the form of exhaust steam, in fact exhaust steam is usually, though not necessarily always, wet steam, depending on the rate of expansion in the steam cylinder of the engine.

Superheated Steam.—Steam heated to a temperature above that of its pressure of saturation is called superheated steam. Superheated steam may be produced by carrying the boiler steam through a coil system where it comes in contact with the heat of escaping fire gases that have a temperature higher than the steam coming from the boiler. Or the steam may be superheated by expanding the saturated steam through a pressure-

Table 10.—Properties of Saturated Steam*

Pressure Lbs. per Sq. In.		Temperature ° F.	Volume Cu. Ft. per Sq. In.	Total Heat of Vapor B. T. U.	Sensible Heat of Liquid B. T. U.	Latent Heat of Vaporization		
Gauge Lbs.	Absolute Lbs.					Internal B. T. U.	External B. T. U.	Total B. T. U.
0.0	14.697	212.	26.81	1151.7	180.0	898.8	72.9	971.7
0.3	15.	213.	26.30	1152.2	181.0	898.1	73.1	971.2
1.3	16.	216.3	24.76	1153.4	184.3	895.8	73.3	969.1
2.3	17.	219.4	23.40	1154.6	187.5	893.5	73.6	967.1
3.3	18.	222.4	22.18	1155.7	190.5	891.4	73.8	965.2
4.3	19.	225.2	21.09	1156.7	193.3	889.3	74.1	963.4
5.3	20.	228.0	20.10	1157.7	196.0	887.3	74.4	961.7
6.3	21.	230.6	19.20	1158.7	198.7	885.4	74.6	960.0
7.3	22.	233.1	18.38	1159.6	201.2	883.6	74.8	958.4
8.3	23.	235.5	17.64	1160.4	203.6	881.8	75.0	956.8
9.3	24.	237.8	16.95	1161.3	206.0	880.1	75.2	955.3
10.0	24.7	239.4	16.51	1162.0	207.5	878.9	75.3	955.7
10.3	25.	240.1	16.32	1162.1	208.2	878.4	75.4	953.8
11.3	26.	242.2	15.73	1162.8	210.4	876.8	75.6	952.4
12.3	27.	244.3	15.18	1163.6	212.6	875.2	75.8	951.0
13.3	28.	246.4	14.67	1164.3	214.6	873.7	76.0	949.7
14.3	29.	248.4	14.20	1165.0	216.6	872.2	76.2	948.4
15.3	30.	250.3	13.76	1165.7	218.6	870.7	76.4	947.1
16.3	31.	252.3	13.34	1166.3	220.5	869.3	76.5	945.8
17.3	32.	254.0	12.95	1166.9	222.4	867.9	76.7	944.6
18.3	33.	255.8	12.59	1167.5	224.2	866.5	76.9	943.4
19.3	34.	257.6	12.24	1168.1	225.9	865.2	77.0	942.2
20.3	35.	259.3	11.91	1168.7	227.7	863.9	77.1	941.0
25.3	40.	267.2	10.51	1171.3	235.8	857.8	77.7	935.5
30.3	45.	274.4	9.41	1173.6	243.1	852.2	78.3	930.5
35.3	50.	281.0	8.53	1175.6	249.8	847.1	78.8	925.9
40.3	55.	287.1	7.80	1177.5	255.9	842.3	79.2	921.5
45.3	60.	292.7	7.18	1179.1	261.7	837.8	79.6	917.4
50.3	65.	298.0	6.66	1180.6	267.1	833.5	80.0	913.5
55.3	70.	302.9	6.22	1182.0	272.2	829.5	80.3	909.8
60.3	75.	307.6	5.82	1183.3	277.0	825.6	80.6	906.2
65.3	80.	312.0	5.48	1184.4	281.6	821.9	80.9	902.8
70.3	85.	316.3	5.18	1185.5	286.0	818.4	81.2	899.6
75.3	90.	320.3	4.905	1186.5	290.1	815.0	81.4	896.4
80.3	95.	324.1	4.663	1187.5	294.1	811.7	81.7	893.4
85.3	100.	327.8	4.442	1188.4	297.9	808.6	81.9	890.5
90.3	106.	332.0	4.202	1189.4	302.3	804.9	82.2	887.1
95.3	110.	334.8	4.057	1190.0	305.1	802.6	82.2	884.8
100.0	115.	337.9	3.900	1190.6	308.3	800.7	82.35	882.3
101.3	116.	338.7	3.857	1190.8	309.2	799.2	82.4	881.6
105.3	120.	341.3	3.735	1191.4	311.9	796.9	82.6	879.5
111.3	126.	345.0	3.566	1192.1	315.7	793.7	82.7	876.4

*Compiled from Kent, 1922 edition.[38]

reducing valve under constant heat. Superheated steam is always dry steam.

Exhaust Steam.—Exhaust steam is the steam discharged from the steam-driven engine, or any discharge steam that has surrendered a portion of its heat units or their equivalent in mechanical energy.

Steam Requirements for Condensing.—For properties of saturated steam above atmospheric pressure, see Table 10. In condensing practice it is assumed that saturated steam generally is used. The following figures illustrate the amount of saturated steam of varying pressures required to condense one pound of water boiling at different vacua and corresponding temperatures.

Pounds of Saturated Steam Required to Evaporate One Pound of Water Using 5.3 Lbs. Steam Pressure per Square Inch

(Evaporating in pan under 23.81 inches of vacuum and with the condense water discharged from jacket and coils at 212° F.)

Heat units required to evaporate 1 lb. water = 1013.5 B.T.U.
Heat units transmitted by condensation of 5.3 lbs. pressure steam = 961.7 B.T.U.
Temperature of 5.3 lbs. pressure steam = 228° F.
Temperature of condense water = 212° F.
Heat units surrendered by condense water = 16 B.T.U.
Total heat units transmitted to milk 961.7 + 16 = 977.7 B.T.U.
Lbs. of steam required to evaporate 1 lb. water $\frac{1013.5}{977.7} = 1.036$ lbs.

Using 10.3 Lbs. Steam Pressure per Square Inch.

Heat units required to evaporate 1 lb. water = 1013.5 B.T.U.
Heat units transmitted by condensation of 10.3 lbs. pressure steam = 953.8 B.T.U.
Temperature of 10.3 lbs. pressure steam = 240.1° F.
Temperature of condense water = 212 ° F.
Heat units surrendered by condense water = 28.1 B.T.U.
Total heat units transmitted to milk 953.8+28.1 = 981.9 B.T.U.
Lbs. of steam required to evaporate 1 lb. water $\frac{1013.5}{981.9} = 1.032$ lbs.

The above calculations show that an increase in the pressure of saturated steam used does not materially change the amount of steam required per pound water evaporated. There is but very slightly less steam required at the higher steam pressure. The per cent decrease at 10.3 lbs. steam pressure as compared with 5.3 lbs. steam is $\frac{(1.036 - 1.032) \times 100}{1.036} = 0.386\%$

It requires 0.386% less saturated steam at 10.3 lbs. steam pressure than at 5.3 lbs. steam pressure to evaporate one pound of water.

An increase in the pressure of saturated steam used does, however, materially increase the rapidity of evaporation, as shown by the following calculations:

10.3 lbs. steam:
Temperature difference between steam and milk
$240.1 - 141.5 = 98.6°$ F.
5.3 lbs. steam:
Temperature difference between steam and milk
$228 - 141.5 = 86.5°$ F.
Increase in temperature difference $= 12.1°$ F.

The temperature difference is directly proportional to the heat transmission. The rapidity of evaporation also is directly proportional to the heat transmission. Hence the increase in temperature difference of 12.1° F. is proportional to the ratio of 86.5 : 98.6 and the per cent increase in rapidity of evaporation in the case of 10.3 lbs. steam over 5.3 lbs. steam is

$$\frac{12.1 \times 100}{86.5} = 13.9\%$$

Relation of Boiler Pressure to Steam Pressure Used in Pan. —The average steam pressure generated in the boiler ranges from about 80 to 120 pounds per square inch. The steam, in order to balance the condensation in the pipes between pan and boiler may be slightly superheated, but in general practice the steam is carried at full boiler pressure to the steam header at the pan.

However, steam at full boiler pressure cannot be used in the pan, because the temperature corresponding to this pressure (100 lbs. pressure saturated steam has a temperature of 337.9° F.) is so high that it would seriously damage the quality of the milk. Also the usual construction of jacket and coils is not of sufficient strength to withstand so great a pressure difference between steam and vacuum in the pan.

It is therefore necessary to reduce the boiler pressure to a pressure suitable for safe operation. A pressure of from about 5 to 15 pounds is generally considered suitable for the purpose. This may be accomplished by merely regulating the valves controlling the steam intakes to jacket and coils. This, however, is a dangerous practice because, in the case of possible obstructions in the discharges, jacket and coils are subjected to the full boiler pressure and also there is always danger of the operator opening the valves too wide, thereby jeopardizing the quality of the milk and inviting accidents. Furthermore, the pressure in jacket and coils will lack in uniformity, fluctuating with the boiler pressure which is subject to wide variations, especially in case of limited boiler capacity.

For ideal conditions, the low pressure side, which is the connection between steam valve and pan, should be of such diameter as to provide the same velocity of the steam as on the high pressure side, which is the line between valve and boiler. This is necessary in order to avoid excessive pressure drop in the steam connections. The total area of all the steam connections should be enlarged proportionally to the increase of the steam volumina from high pressure to low pressure. Each connection should also have a valve and gauge on the pan side of the header.

A better way of insuring a uniform steam supply of low pressure is to install an automatic pressure reducing valve on the boiler side of the steam header. By means of this valve the steam pressure may be reduced to any desired point. Reducing valves are available that maintain a constant pressure independent of variations of boiler pressure.

In this case the pressure reduction takes place in the main steam line, and the header is on the low pressure side, so that all pan connections receive a uniform low-pressure steam. Here, too, the velocity of the steam should be kept constant by enlarging the low pressure side of the reducing valve. This may be conveniently illustrated by the following example:

One pound of saturated steam at a boiler pressure of 100.3 lbs. occupies 3.857 cubic feet. One pound of saturated steam of 10.3 lbs. pressure occupies 16.32 cubic feet. Therefore, the necessary increase in size of connections for the ideal area of the low pressure side of the reducing valve would be $\frac{16.32}{3.857}=4.23$ times the area of the high pressure side. If the proper diameter of the high pressure side is 3 inches, then the proper diameter of the connection between reducing valve and header should be at least 6 inches. A properly designed steam header should always be larger than the supply line. In this case it should be about 9 inches in diameter and the connections to the pan should be proportional in diameter to the heating surface of the respective coils and jacket, so as to maintain a constant steam velocity. The header should be equipped with a safety valve and gauge, and each individual connection should have a valve and gauge on the pan side.

Relation of Gauge Pressure to Steam Temperature when Steam Is Reduced.—When reducing the pressure of dry saturated steam from boiler pressure to suitable pan pressure, the steam must be allowed to expand. Disregarding the loss of heat due to radiation, the steam expands through the pressure-reducing valve without loss of heat, and it passes on under the same velocity. This process progresses under constant heat. That is, one pound of steam contains the same heat units on both high pressure and low pressure side of the valve. This is so, because no heat units are removed, or converted into mechanical energy.

After the steam has passed the reducing valve, the temperature of the now low-pressure steam is higher than the corresponding pressure. This is due to the liberation of heat units by expanding under constant heat. For instance, one pound of 100 lbs. pressure saturated steam contains 1190.6 B.T.U. One pound of 10 lbs. pressure saturated steam contains 1162.0 B.T.U. Therefore, by reducing the pressure from 100 lbs. to 10 lbs. 1190.6 — 1162.0 = 28.6 B.T.U. are liberated. Since this heat is not taken out of the steam, it is utilized to superheat the steam on the low pressure side.

By using the Mollier entropy diagram we find that 28.6 B.T.U. will raise the temperature of the low pressure steam 62.98° F. above its corresponding saturation temperature. Since the temperature of saturated steam of 10 lbs. pressure is 239.4°

F., the total temperature of this low pressure steam will be 239.4 + 62.98 = 302.38° F.

The temperature difference of 62.98° F. is brought about by the liberation of the difference in properties of saturated steam by expanding from 100 lbs. pressure to 10 lbs. pressure. This difference of 62.98° F. corresponds to 28.6 B.T.U. Thus the specific heat of the steam due to this pressure caused by expansion at a constant heat is $\frac{28.6}{62.98} = 0.4541$ B.T.U. In other words, it takes only about one-half B.T.U. to raise the steam temperature 1° F. above its saturation temperature. The specific heat of steam varies with the pressure of the original saturated steam (boiler steam) and the ratio of expansion, as shown in tables and charts by Marks and Davis[133] of the properties of superheated steam.

The fact that the superheated steam of a pressure of 10 lbs. has a temperature of 302.38° F. emphasizes further the fact that this temperature in this case does not correspond with the gauge pressure of saturated steam. In the case of saturated steam the temperature for the corresponding pressure of 10 lbs. would be 239.4° F. On the other hand, the corresponding pressure for superheated steam with a temperature of 302.38° F. would be 54.8 lbs.

Such a temperature (302.38° F.) corresponding to a saturated steam pressure of 54.8 lbs. would be justly considered too high for vacuum pan work, especially in the case of pans in which all the steam inlets are located on the same side. This would cause exposure of the milk to excessive temperature.

The important point here is that the measurement of the steam by the gauge may be very misleading from the standpoint of actual temperature. 10 lbs. pressure, reduced from 100 lbs. saturated steam pressure to 10 lbs. superheated steam pressure, has a temperature much higher than 10 lbs. pressure of saturated steam.

It should be understood, however, that in this case of superheated steam, the heat units above those of the properties of saturated steam are transmitted to the milk without causing a drop in pressure until the point of saturation is reached. Each pound of steam has 28.6 heat units of superheat to transmit without forming any condensation. The liberation of the superheat reduces the temperature of the steam from 302.38° F. to

239.4° F. quickly, because the specific heat of superheated steam in this case is found to be only 0.4541 B.T.U. Therefore, each B.T.U. of one pound of steam results in a temperature drop of about 2° F. until the saturation point is reached. For this reason the milk is exposed to high temperature of the superheated steam over the first few inches of the coil only, where the steam surrenders its superheat.

Another factor that tends to modify the high temperature of the low pressure superheated steam is heat loss by radiation due to incomplete insulation. The above discussion is all based on the assumption that there are no heat losses between the pressure-reducing valve and the pan. In practical operation and even under conditions of high grade insulation, there is bound to be some loss of heat due to radiation. The longer the distance and the less complete the insulation, the greater the loss of heat due to radiation.

Transforming Superheated Steam into Saturated Steam.—Since it is undesirable to use such high temperature steam as results from reducing the pressure of boiler steam from 100 lbs. to 10 lbs., it is advisable to convert the superheated steam so formed into saturated steam. This may be done by injecting into the superheated steam the proper amount of water. A fine spray of a small amount of water is directed against the flow of the superheated steam. The water spray can be regulated by means of a thermostat set for constant temperature of the new saturated steam thus formed.

The use of water for reducing the temperature of the superheated steam to the saturation point of the steam under a given pressure does not cause any loss or waste of heat units. It merely lowers the temperature of the steam by increasing its volume and this increase in volume compensates for the drop in temperature.

The Utilization of Exhaust Steam in Vacuum Pan Operation.—Wherever possible, the exhaust steam available in the condensery should be utilized for condensing purposes. This is made possible because the evaporation of the milk is done in a vacuum, in which the milk boils at a relatively low temperature. This provides a comparatively wide temperature difference between milk and steam, even when low-temperature steam, such as exhaust steam, is used.

Under most factory conditions it is preferable to use the exhaust steam in conjunction with boiler steam, rather than exhaust steam exclusively. But where exhaust steam alone is to

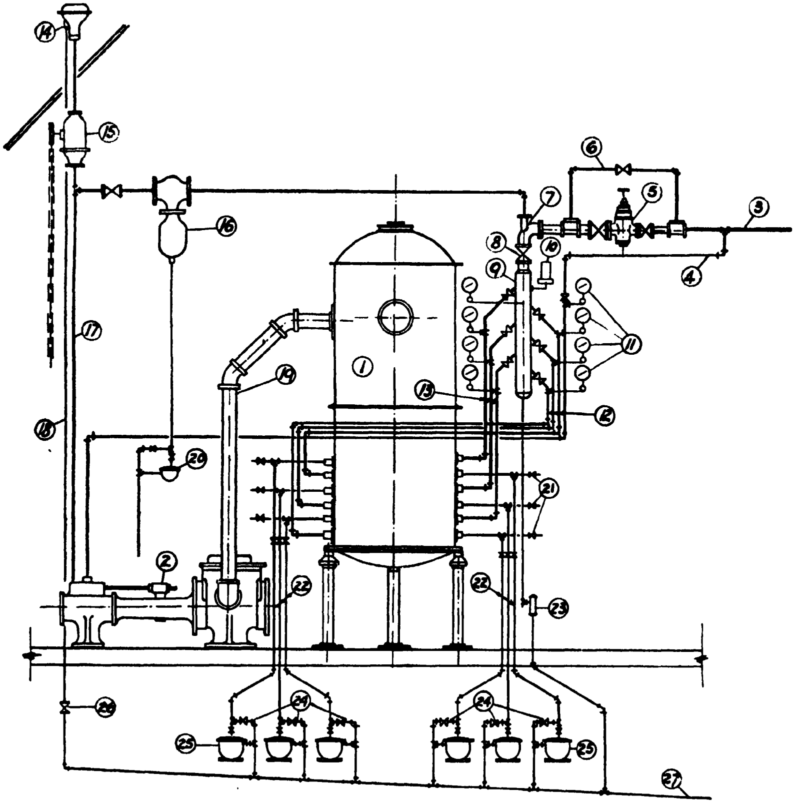

Fig. 45. Vacuum pan with exhaust steam connections
Courtesy of Arthur Harris & Co.

be used, provision must be made for a large steam header and full size connections to jacket and coils and the use of specially designed, short coils.

In the steam line from vacuum pump, or other source of exhaust steam, to header, there must be suitable provision for the discharge of condense water, such as by installation of condense water traps. The use of exhaust steam alone is seldom practical, however, because of the usually too limited supply, its constant variation in both volume and pressure and the wet character of the exhaust steam that is generally available.

In order to use exhaust steam to the best advantage, therefore, it is advisable to use boiler steam in connection with the available exhaust steam. The exhaust steam may thus be supplemented by injecting boiler steam into the main exhaust steam line leading to the header. The injection of the boiler steam is controlled by a pressure regulator in order to maintain a constant pressure. The supply of boiler steam is thus automatically governed by the supply of exhaust steam. As the supply of exhaust steam decreases, more boiler steam is automatically supplied.

An additional advantage of injecting boiler steam into the exhaust steam is that it improves the quality of the exhaust steam by utilizing the heat units liberated by the expanded boiler steam, thus converting the exhaust steam into dry saturated steam.

By utilizing the exhaust steam and economizing the fuel requirements, the efficiency of the engine or pump supplying the exhaust steam is decreased. This is due to the back pressure under which the exhaust steam is discharged into the supply line to the pan, as against its otherwise free discharge into the atmosphere, or into the usual condenser.

This problem of back pressure, therefore, must be given consideration when selecting the steam equipment from which exhaust steam is to be utilized. The size of such equipment should be proportional to the back pressure under which the engine or pump must operate. A suitable installation for using both, exhaust steam and boiler steam, is shown in the accompanying illustration.

The utilization of exhaust steam without back pressure on the steam-driven engine may be arranged also by using the vacuum system of discharging the condense water from jacket and coils, as explained under the caption, "Steam Traps" in succeeding paragraphs, or by the installation of a thermo-compressor in the place of the ordinary steam injector. The function of the thermo-compressor is to compress the exhaust steam on the pan side, from the pressure under which it is discharged from the steam engine, to the desired pressure for pan operation.

The thermo-compressor operates best under constant supply of steam.

Steam Traps.—The economic operation of the pan demands that all the water condensed in jacket and coils be returned to the boiler, thus saving the heat units (sensible heat) contained in the condense water and avoiding the well known disadvantages of feeding the boiler with cold water.

The continuous discharge of the condense water from jacket and coils, without loss of steam, is made possible by the use of a suitable steam trap. The steam trap is an automatically controlled valve, the function of which is to allow the discharge of water and to prevent the escape of steam.

Each coil and the jacket should have an individual steam trap, located below the condense water outlet. In case there is only one steam trap for all condense water outlets, there should be provided individual air vents for each condense water outlet.

The condense water usually discharges from the steam traps under atmospheric pressure and returns to the boiler feed water tank by gravity. From this tank it is pumped into the boiler. Instead of discharging the steam traps into the atmosphere, a vacuum system may be used. In this case a vacuum pump is attached to the discharge of the steam trap. This has the additional advantage of reducing the back pressure on the steam-driven engine supplying the exhaust steam.

Multiple-Effect Evaporators.—The completeness and economy of steam utilization may be greatly increased by the use of multiple-effect evaporators. These evaporators consist of condensing units of two or more pans, installed in tandem formation and connected with one another so as to cause the milk to flow from the first pan to the second, from the second pan to the third, etc.

The first pan (first effect) is supplied with steam from boiler or exhaust steam from engines. The second pan (second effect) is heated by the vapors arising from the milk in the first pan. Thus, the latent heat of the vapors from the boiling milk in the first pan is utilized to heat the milk in the second pan. The latent heat of the vapors from the boiling milk in the second pan is utilized to heat the milk in the third pan, and this performance is repeated with each additional pan in the unit, each pan except the first, acting as a condenser for the preceding one.

The boiling temperature is highest in the first pan and diminishes with each succeeding pan. Thus in the triple-effect unit the operation is approximately as follows: First pan 3.5 inches vacuum and about 200° F., second pan 14 inches and about 180° F., third pan 26 inches of vacuum and about 120° F.

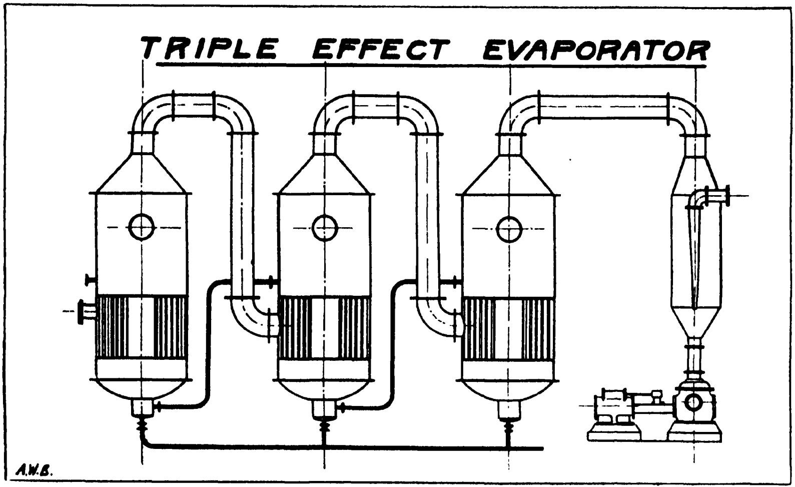

Fig. 46. Multiple-effect vacuum pan unit
Courtesy of Arthur Harris & Co.

The multiple-effect evaporator has not as yet been adopted by the condensed milk industry. Its chief objection lies in the relatively high temperature at which the milk would have to be condensed in the first pan. However, the multiple principle would lend itself advantageously to the condensing of such by-products of milk as buttermilk,.the market value of which is not materially affected by the presence of a cooked flavor in the finished product, while the economy of manufacture would be very considerably greater.

Disregarding the possible heat loss by radiation, the double-effect evaporator reduces steam consumption to 50 per cent and the triple-effect system lowers steam consumption to 33 per cent of that incurred by the use of the single effect unit. As shown in Chapter VI the recompression evaporator combines the advantages of steam and water economy of the multiple effect evaporator with the desired low-temperature concentration of the single effect principle. See also "Multiple-Effect Down-Flow Evaporator p. 103.

CHAPTER VIII

VACUUM PAN OPERATION

After the milk has been properly standardized, and fore-warmed at the desired temperature, and after the correct amount of sugar has been added to and thoroughly dissolved in it, it is drawn into the vacuum pan for condensing.

CONDENSING THE MILK

Starting the Pan.—Before drawing the milk into the pan, the pan should be thoroughly rinsed with water, then steamed until the temperature rises to about 180° F. or above. Then the manhole cover is put in place, all the air valves are closed, water is turned into the condenser and the vacuum pump is started. When the vacuum gauge shows about twenty inches of vacuum, the pan is ready for the milk. See also "Vacuum Pan Sanitation," later in this chapter.

Operating the Pan.—The valve of the milk pipe leading to the pan is now partly opened. The milk enters the pan automatically as the result of the reduced pressure in the pan. When the milk covers the jacket, steam is gradually turned into the jacket. As each coil becomes submerged in the milk, it is charged with steam. At no time should steam be turned on jacket or coils when they are not completely covered with milk, as such operation would cause the milk to stick to and burn on the heating surface.

At the start the steam pressure on jacket and coils should be held low, so as to avoid the danger of cooking on, owing to the presence in the rapidly incoming fresh milk of considerable air. As this air is removed and the milk "settles down" to uniform boiling, the steam pressure may be gradually increased until it reaches the maximum suitable for use. Because of the sensitiveness of milk to heat it is preferable to use as low steam pressure as possible, consistent with maximum rapidity of evaporation. This in turn is governed by size and arrangement of heating surface as explained in previous chapters, and by the temperature and volume of cooling water available.

It is now generally recognized that from 5 to 10 pounds of saturated steam pressure is the maximum that is advisable to use for safe and economical operation of vacuum pans properly constructed and equipped with adequate heating surface. Pans with inadequate heating surface, or heating surface poorly arranged or of faulty design, may require the use of considerably higher steam pressure to accomplish reasonably rapid evaporation.

The fluid milk contains considerable quantities of air. This causes foaming and a drop in the vacuum during the early operation. If this milk is drawn into the pan very rapidly, as is the case when opening the milk valve wide, there is danger of heavy entrainment losses. This is best avoided by opening the milk valve only partly, or by watching the behavior of the milk in the pan very closely and admitting a small amount of air through the vacuum brake whenever the milk rises dangerously high. This difficulty occurs only at the start. The air is removed quickly and the vacuum returns to normal. During the early stages of the process, when the milk is of low density, the evaporative duty of the pan is high and evaporation goes on with maximum rapidity. This gradually decreases and is lowest toward the end of the process.

When enough milk is in the pan to completely cover the coils, the milk intake should be reduced and regulated in accordance with the rate of evaporation. The milk is drawn into the pan continuously, but only as fast as it evaporates. It should be kept as much as possible at a constant level, and this level is preferably as low as is consistent with complete covering of the uppermost coil. Carrying the milk at an excessively high level makes uniform operation difficult. It tends to diminish the speed of evaporation and it augments the danger of entrainment losses.

The temperature at which the milk is condensed should be relatively low. This is desirable and necessary in order to preserve in the condensed milk the natural flavor and color of fresh milk and to prevent the appearance of a cooked flavor and dark color. Low temperature of milk also insures a wide temperature difference between milk and steam. This augments the heat transmission per square foot heating surface per hour and, therefore, increases the rapidity of evaporation. For these reasons the pan should be operated at the lowest temperature consistent with reasonable economy of water. See also "Amount of Water Required to Condense One Pound of Vapor," Chapter VI.

This temperature lies within the range of about 130 to 145° F. corresponding approximately to a vacuum of about 27″ to 24″, respectively. Within reasonable limits the temperature of the milk in the pan is readily controlled by the amount of water admitted to the condenser. If the temperature rises above that desired, an increase of the water supply to the condenser will lower it and vice versa. There is a limit, however, to the increased volume of water that will lower the temperature in the pan as explained in Chapter VI.

The pan temperature is influenced also by the steam supply, the presence of air leaks and the performance of the vacuum pump. A sudden rise in temperature may be due to irregularities in boiler pressure, or to the water supply to the condenser running low permitting the entrance of air, or to air leaks in pan or milk draw pipe, or accidental irregularities in the functioning of the vacuum pump.

By the time all the milk is in the pan, condensation is nearly completed, and from ten to twenty minutes further boiling usually gives the milk the desired density. Toward the end of the process the steam pressure in jacket and coils should be gradually reduced. When the milk approaches the desired density, it is comparatively heavy and viscous, it boils less vigorously and its movement is more sluggish. Each particle of milk is exposed to the heating surface for a longer time. In the case of excessive steam pressure, its quality is jeopardized. If the batch is small so that the level of the milk drops below some of the coils, steam to each exposed coil should be turned off entirely as soon as the coil becomes visible. It is advisable also to permit the temperature to drop when the end point approaches, so as to minimize the tendency of this viscous product to superheat.

STRIKING OR FINISHING THE BATCH

Definition.—When the boiling milk in the vacuum pan approaches the desired degree of concentration, the batch is "struck." The term "striking" is applied to the operation of sampling the condensed milk and testing the sample for density. This term very probably referred, originally, to the meaning of "striking the batch right," that is, stopping the process at the proper time, or when the milk is neither too thick nor too thin. It then expressed the result of the operation, while now it is used to mean the operation itself.

Ratio of Concentration.—Sweetened condensed milk intended for canned goods has a specific gravity of about 1.30. This density is reached usually when the ratio of concentration is about 2.5 : 1, i. e., 2.5 parts of fresh milk are condensed to one part of condensed milk, assuming that about 16 pounds of sucrose have been added to every one hundred pounds of fresh milk.

This ratio of concentration is somewhat higher than is now practiced in American condenseries supplying the domestic markets. Since the introduction of practical and accurate methods for standardizing the product to a definite and exact standard of composition, the trend of the industry has been to adopt the Federal Standard of 20% milk solids not fat and 8% fat, as the maximum content of solids and fat for sweetened condensed milk and to compensate the decrease in milk solids by a corresponding increase of sugar. American sweetened condensed whole milk contains now approximately 44.5% sugar and the ratio of concentration is approximately 2.33 to 1. Sweetened condensed milk containing 28% total milk solids, 8% fat and 44.5% sugar has a specific gravity at 120° F. of 1.2853.

Methods.—To know just when the proper degree of concentration has been reached is difficult and requires experience. It is here where the processor can easily make or lose his wages. There are various indications reminding the observing pan operator that the milk in the retort is nearly "done," viz., time consumed for condensing, time elapsed since all the milk has been "drawn up," amount of condensed milk left in the pan. Likewise, temperature and vacuum are under better control, there is a tendency for the temperature to drop and the vacuum to rise, and less water is needed in the condenser; the vacuum is about one inch higher than the theoretical vacuum for the same recorded temperature (see Table 9). The behavior and appearance of the boiling milk at this point is characteristic.

The milk has settled down to a quiet boil. It assumes a glistening, glossy lustre and there is a heavy roll from periphery towards center, forming a small nucleus or puddle of foam in the center of the pan. An experienced and observant operator knows within a fraction of a minute when the milk is condensed enough. This does not mean, however, that he should wait until the last minute before he "strikes" the batch, for even the most skillful and experienced processors may be deceived by the mere appearance of the condensed milk through the sight glass For beginners and inexperienced operators, particularly, there is wisdom in starting to sample early enough to have sufficient time for taking several samples in succession.

Striking by Appearance to Eye.—Prior to the practice of standardizing the sweetened condensed milk to a definite percentage of total solids, the experienced eye and good judgment of the processor were practically the sole criterions of the correct point of concentration at which the condensing process was to be stopped. Striking then was confined to one or the other of the following methods:

Draw a sample from the pan into a dipper; lower the dipper into a pail of ice water or snow. Stir the sample rapidly with a metal-back thermometer until cooled to 70° F. Note the thickness; or,

Draw a sample from the pan into a cup. Note the appearance when allowing to pour from a teaspoon. The translucency of the milk when thus held in a thin film against the light and the manner and extent of "piling up" in the cup when flowing from the raised spoon served as the index to the consistency of the milk. Remarkable uniformity of consistency from batch to batch was obtained by experienced pan strikers by these crude methods.

Mechanical Devices for Striking.—Several mechanical devices and methods have been found useful for determining the density of sweetened condensed milk at the pan. To these belong the picnometer method, the hydrometer method and the refractometer method.

The **Picnometer** method determines the weight of a definite volume of sample by filling a suitably constructed cup of known capacity and weighing it on sensitive scales. This method has been found quite accurate and reasonably rapid. It is successfully used by some pan operators.

The **Hydrometer** method is probably the most popular method used in American condenseries. For this the Baumé hydrometer, especially graduated for sweetened condensed milk, is used. It is simple and rapid and yields fairly accurate readings.

The **Refractometer** method is of more recent introduction in the condensery. Its adaptation for the determination of the density of sweetened condensed milk was developed by Rice and Miscall.[273] It is in successful use in a number of condenseries and has been found an accurate and rapid means of determining the proper point of striking.

The Use of the Baumé Hydrometer.—The Baumé hydrometer suitable for use for sweetened condensed milk has a scale ranging from 30 to 37° B., or from 30 to 40° B. In exceptional instances a wider scale range is provided (26-37°). It is graduated to .1° B.

Accurate standardization of the composition of the fluid milk to a definite ratio of fat to solids not fat and the adoption of a definite composition of the condensed product have not only facilitated but made more serviceable the use of the Baumé hydrometer when finishing the batch. Mojonnier and Troy[42] determined, by careful analyses, the Baumé reading at different temperatures, of sweetened condensed whole milk and sweetened condensed skimmilk, as related to percentage of fat, solids not fat, and total solids. They show that sweetened condensed whole milk testing 8% fat, 20% solids not fat and 72.5% total solids has a Baumé reading at 120° F. of 32.2°, while sweetened condensed skimmilk testing 0.5% fat, 27.5% solids not fat and 70% total solids has a Baumé reading at 120° F. of 35.7°. The same authors further show that 0.1° Baumé is equal to approximately 0.27% total solids in sweetened condensed whole milk, and 0.2% total solids in sweetened condensed skimmilk of the above composition, respectively.

In order to avoid inaccuracies in the evaluation of the Baumé reading, the readings should be standardized to a uniform temperature. A temperature of 120° F. appears the most convenient at the time of striking the batch. When it is not practicable to so adjust the temperature in the pan at the time the sample is taken to have the sample at 120° F., a correction may readily be made that will give the equivalent Baumé reading at the adopted Standard temperature (in this case at 120° F.). Every degree Fahrenheit is equal to approximately 0.025° B. If the actual temperature at reading is above 120° F. add to, if it is below 120° F. deduct from, the actual reading.

Example: Baumé reading at 132° F. is 32.° What is the corrected reading at 120° F?

The temperature of actual reading was $(132 - 120) = 12°$ F. too high. The corrected reading at 120° F. is $32 + (12 \times 0.025) = 32.3°$ B.

Sampling of the Batch.—The samples are usually drawn from the bottom of the pan by operating the two valves at the outlet as explained in Chapter VI on "Description of Vacuum Pan." The sample is drawn directly into the container in which it is tested for consistency or density. Where the Baumé hydrometer is used the sample is drawn into the hydrometer jar and the Baumé is inserted.

For greater convenience, particularly where the pan is elevated at a considerable height above the main floor, an especially constructed sampling cup or "striking cup" attached to the lower part of the pan body may be used. The striking cups are now furnished of such design and size as to permit the Baumé hydrometer to float in them, rendering the use of a separate hydrometer cylinder unnecessary.

Finishing the Batch.—When the milk in the pan is approaching the desired point of concentration it is desirable to diminish the steam pressure on jacket and coils, bringing the temperature down to near the standard "striking" temperature of 120° F.

As soon as the desired density is reached the steam is immediately shut off and the "blow-down" valve or vacuum break is opened; the water to the condenser is turned off and the vacuum pump is stopped. The manhole cover is removed and the vacuum pump started again to remove the hot air over the milk.

The condensed milk should be drawn off immediately and rapidly to prevent superheating while remaining in the hot pan, which invites objectionable thickening and might jeopardize the quality of the product. The following table shows the specific gravity of varying degrees Baumé ranging from 28°B. to 37.8°B. at 60° F.

Table 11.—Specific Gravity of Sweetened Condensed Milk of Different Baumé Degrees.

Baumé at 60° F.	Specific Gravity	Baumé at 60° F.	Specific Gravity
28.0	1.2407	33.0	1.2965
.2	1.2428	.2	1.2988
.4	1.2449	.4	1.3011
.6	1.2471	.6	1.3034
.8	1.2493	.8	1.3058
29.0	1.2515	34.0	1.3082
.2	1.2536	.2	1.3106
.4	1.2558	.4	1.3130
.6	1.2580	.6	1.3154
.8	1.2602	.8	1.3178
30.0	1.2624	35.0	1.3202
.2	1.2646	.2	1.3226
.4	1.2668	.4	1.3250
.6	1.2690	.6	1.3274
.8	1.2713	.8	1.3299
31.0	1.2736	36.0	1.3324
.2	1.2758	.2	1.3348
.4	1.2780	.4	1.3372
.6	1.2803	.6	1.3397
.8	1.2826	.8	1.3422
32.0	1.2849	37.0	1.3447
.2	1.2872	.2	1.3472
.4	1.2895	.4	1.3497
.6	1.2918	.6	1.3522
.8	1.2941	.8	1.3548

Standardizing to the Desired Percentage of Total Solids.—If it is desired to standardize the milk to an exact per cent of total solids in the finished product, the condensing process may be carried slightly beyond the correct point of concentration.

The condensed milk is then drawn from the pan into a drop tank on scales, where it is weighed, and tested for total solids. The standardizing is accomplished by adding to the batch the amount of water necessary to reduce the per cent total solids present to that desired in the finished product, as shown by the following example:

Example.—The batch of sweetened condensed milk in the drop tank weighs 3539 lbs. and contains 73.4% total solids. Using the example given under "Calculations of Amount of Sugar to Add," Chapter IV, the finished product must contain not less than 72% total solids in order to have the milk solids conform with the Federal standard of 28%. How much water must be added to this batch to reduce the total solids from 73.4% to 72%?

Answer:

Lbs. of water needed is $\left(\frac{73.4 \times 3539}{72}\right) - 3539 = 68.8$ lbs.

Proof:

Batch weighs	3539.0 lbs. tests 73.4% T.S., contains	2597.626 lbs. T.S.
Water added	68.8 lbs.	
Total	3607.8 lbs. containing	2597.626 lbs. T.S.

Per cent total solids in batch is $\frac{2597.626}{3607.8} \times 100 = 72\%$

PAN OPERATING PRECAUTIONS

General Precautions in Pan Operation.—Aside from the fundamental factors of design of pan and condenser, area and arrangement of heating surface, steam supply and control, efficient removal of condense water from jacket and coils, water supply to condenser, etc., all of which were discussed in detail in previous chapters, efficiency of operation, prevention of costly accidents, and protection of quality of finished product, depend in a large measure on the proper care of the pan during and between operations.

Milk Coating on Heating Surface.—The pan can do efficient work only so long as its heating surface is kept free from deposits of coagulated milk.

Such deposits may be due to any one of the following causes: too high acidity of milk, milk containing colostrum, successive condensing of too many batches before cleaning the pan, turning steam on jacket and coils before they are covered with milk, too high steam pressure, keeping steam on coils too long toward the end of the run, leaky steam valves.

High acid milk is abnormally sensitive to heat, coagulating at temperatures at which milk of normal acidity is not noticeably affected. Such milk has an inevitable tendency to coat the steam heated jacket and coils. The prevention here lies in more rigid inspection on the receiving platform. Properties of the milk other than acidity may materially influence the caking of milk on the heating surface. These properties usually have to do with high albumin content and the possible presence of colostrum. They occur usually in the spring and early summer when the majority of the cows have recently freshened. It is a fact well known to the experienced pan operator, that spring and early summer milk shows this tendency of coating the coils very pronouncedly. Not infrequently layers of a gelatinous milk one-half inch thick may cover the heating surface. This phenomenon is usually entirely absent in late summer, fall and winter. The tendency for a coating of milk to adhere to the heating surface is augmented when batch after batch is condensed without rinsing or washing the pan between batches. Efficient cleaning of the pan and thorough rinsing down between batches is time well spent. In the absence of these precautions, the increasing thickness of the milk film that builds up on the heating surface, insulates the latter, diminishing heat transmission. It prolongs the time required for condensing, causes loss of milk solids and jeopardizes quality.

Exposure of the coils to air during pan operation causes the burning of milk on to the heating surface. This may happen at the start when the milk is foamy and when steam is turned on before the milk is completely covering the respective coils. Or it may occur when the steam is not turned off from the coils as fast as the gradually receding level of the milk begins to expose them, or if the steam valves leak. Likewise, in case of accidental interruption of the operation of the process, milk will burn on the heating surface, if the steam is not immediately shut off. Using too high steam pressure on jacket and coils will also produce this defect.

Any condition that causes the coating of the milk side of the heating surface diminishes the efficiency of heat transmission, prolongs the condensing process and may seriously damage the quality of the finished product.

Entrainment Losses.—These losses have to do with milk spray being carried over into the condenser and out of the pan with the cooling water. The usual operating causes of entrainment losses are: too rapid intake of fluid milk, carrying the milk at too high a level in the pan, sudden and large air leaks, improper operation of the pan. The difficulty is frequently augmented and prevention hindered by a faulty construction of the pan.

As explained in Chapter V, the danger of heavy entrainment losses is remote in pans with proper design of milk intake, coils, vapor belt and vapor connection to condenser, provided that the milk in the pan is carried at a reasonable level. One of the most common causes of excessive entrainment losses due to faulty design is inadequate heighth of the pan body or vapor belt. Losses as high as 2% milk solids are not uncommon in the operation of such pans. The most effective way to eliminate these losses lies in extension of the vapor belt to an adequate height. This means of eliminating excessive entrainment losses is preferable to the installation of a milk trap between pan and condenser, because of the difficulty of keeping the milk trap in sanitary condition. The danger of loss of milk is less also in the case of pans with inside condenser because of the greatly reduced velocity of the vapors, minimizing the tendency of the milk spray being carried over into the condenser.

The occurrence of excessive entrainment losses is usually detected by the milky condition of the water seal of the piston glands of the vacuum pump. However, the absence of milkiness does not necessarily insure absence of entrainment losses, as the dilution of any milk carried over into the cooling water is so great, that even a considerable loss of milk may not give the water seal a noticeably milky appearance.

Inefficient Functioning of Vacuum Pan.—Abnormal foaming of the milk in the pan is usually caused by air leaks into the pan. Foaming is usually accompanied by low vacuum and high temperature. Air leaks may occur in the fittings of the milk suction pipe, in joints, fittings and valves of the pan, at the manhole cover, through cracked or leaky spy-glasses. A sudden drop in vacuum and rise in temperature, however, is usually caused by larger leaks, such as air entering the condenser due to the water supply running low, or air coming in through the milk draw pipe because of too low a level of the milk in the hot well, or the formation of a swirling vortex around the suction end of the milk draw pipe, or the breaking of a spy-glass, or the accidental stopping of the vacuum pump, or low boiler pressure on the steam ejector, etc.

In all cases of a sudden drop of vacuum and rise of temperature, costly loss of milk may be prevented by immediately shutting off the steam supply to jacket and coils and closing the milk intake. When the cause of the air leak has been removed, the vacuum pump, assisted by the water spray in the condenser, will gradually reestablish the desired vacuum. The tendency of the milk to rise in a body and threaten to rush over into the condenser at such times is readily controlled by quickly letting a little air in through the vacuum break whenever the milk rises to a threatening level. Alertness and proper handling by the operator will soon break the tension of the milk and cause it to resume normal boiling.

Abnormally slow condensing is likewise due to air leaks, but in addition, it may be caused by the steam traps not functioning properly, such as may occur when the steam condensate is forced up high, causing back pressure and thus preventing proper drainage of condensate from the coils. Condensation from traps should be allowed to run into an open tank located at the same or at a lower level. The proper insulation of the pan, including bottom, vapor body and dome, further assists in fuel economy and speed of evaporation.

Vacuum Pan Sanitation.—The vacuum pan needs a complete and thorough cleaning after each day's work. As soon as the last batch has been drawn off and while the interior of the pan is still wet, run sufficient water in it to completely cover the coils. Add a small amount of tri-sodium phosphate or other casein solvent. Allow to soak as long as the routine of work permits. Then empty the pan and scrub all surfaces until all remnants of milk are removed. In some factories the practice prevails to allow the pan to soak over night. In this case the washing powder used should contain a small amount of sodium chromate or silicate to insure complete protection of all tin-soldered seams against corrosive action and weakening.

When washing the pan, the less accessible dome and goose neck should not be overlooked. These parts have also come in contact with the milk spray during pan operation and if the film of sugar, acids and milk constituents that covers their inside surfaces is allowed to remain, there is action on the copper, especially in the presence of air, between operating days. Copper oxides and salts form. These are readily soluble and if not removed, will rinse down into the next day's batches of milk, causing the condensed milk to show an abnormally high copper content, which jeopardizes its flavor, keeping quality and wholesomeness. Unless the pan is constructed of a corrosion resistant metal that has no effect on the milk it is advisable to tin plate the dome and goose neck. See also Chapter II on "Metals in Condensery Equipment."

Fig. 47. Man-hole cover for sterilizing pan
Courtesy of Arthur Harris & Co.

After the pan has been thoroughly cleaned, rinse its entire interior, including dome and goose neck, with clear water and then steam it. Keep the manhole and the outlet valves at bottom of pan open to permit air circulation, draining and drying over night. The next morning, before the milk is allowed to enter, repeat the rinsing and steam treatment. It is good practice to fasten the manhole cover with special clamps and steam the pan under several pounds of pressure, provided that the spy-glasses have the necessary clearance for expansion (about ¼ inch) to prevent breakage at the high temperature.

CHAPTER IX

COOLING SWEETENED CONDENSED MILK

The cooling process is an important phase in the successful manufacture of sweetened condensed milk. Prompt cooling is necessary not only to avoid superheating, excessive thickening and darkening of color, but on the manner of cooling depends, in a large measure, the smoothness of texture of the finished product.

At vacuum pan temperature (130°-140° F.) the sweetened condensed milk of average composition represents practically a saturated solution of sugar of milk. At room temperature this milk sugar solution is highly supersaturated. There is more milk sugar present than the water contained in the condensed milk is capable of holding in solution.

As the temperature drops, therefore, there is an inevitable tendency for a portion of the milk sugar to crystallize out. This crystallization will of necessity continue until all of the milk sugar present in excess of the saturation point, at the temperature to which the milk has been cooled, is precipitated out. Crystallization, however, does not progress uniformly at the rate the milk is cooled.

During the early stages of cooling the amount of milk sugar present in excess of saturation is small and the crystals form slowly. As the temperature drops, supersaturation increases and the rate of crystallization becomes more rapid, reaching its maximum at approximately 86° F. As the drop in temperature continues, the increasing viscosity of the milk retards crystal formation and the velocity of crystallization decreases until sometime after the final cooling temperature has been reached. The exact temperature at which the rate of crystallization is highest varies with the ratio of milk sugar-to-water in the sweetened condensed milk, which in turn is largely controlled by concentration of milk solids and sucrose content.

The size of the milk sugar crystals controls the smoothness of texture of the finished product. If the crystals are exceedingly small the product is smooth and velvety as it should be; if they are large, or if large crystals are present in considerable numbers, the product assumes an objectionable, coarse, sandy texture.

Immediately after cooling, the milk always shows a smooth texture, regardless of the manner of cooling. It is only upon prolonged standing that the improperly cooled product becomes sandy. This is due to the fact that it takes time for the crystals to grow to sufficient size to coarsen the texture of the milk. It is this development of sandiness after cooling that must be prevented in order to insure a product of dependable, permanent smoothness of texture.

Mass Crystallization in Cooling.—The problem of making milk of smooth texture, therefore, is not a problem of guarding against crystallization of the milk sugar during the cooling process; it is a problem of preventing the crystals present at the conclusion of the cooling process from growing in size subsequently. It is a problem, therefore, of providing conditions in the cooling process suitable for mass crystallization. So great a multitude of small crystals must be formed as to reduce the state of supersaturation to a state of saturation by the time the cooling is completed, thus eliminating the excess of sugar in solution and precluding the possibility of further crystal growth after cooling.

The Forced Crystallization Period.—In commercial manufacture, mass crystallization of milk sugar may be accomplished by retarding and prolonging the cooling under continued vigorous agitation when the temperature has been lowered to the point where crystal formation is most rapid, or by seeding the milk with milk sugar crystals, or both.

This intermediate or forced crystallization period in the process of cooling should occupy approximately 45 to 60 minutes. In other words, when the condensed milk has been cooled rapidly from pan temperature to about 86° F., the cooling for the next 45 to 60 minutes is slowed down sufficiently to prevent the temperature from dropping below 75° F. during this intermediate period.

Seeding the Condensed Milk.—Mass crystallization during the intermediate period is much accelerated by seeding with milk sugar crystals. This is best done by the addition to the condensed milk of from two to three gallons of condensed milk from a previous day's batch, or of from four to five ounces of powdered milk sugar, per 1000 pounds of condensed milk to be cooled. This seed material should be added at the beginning of the intermediate period, i. e., at a temperature of about 86° F.

Importance of Vigorous Agitation.—The condensed milk should be continuously and vigorously agitated during the forced crystallization period. This is necessary regardless of whether seeding is practiced or not. Agitation enhances mass crystallization. After the forced crystallization period, cooling to the desired temperature may be continued as rapidly as facilities permit, but the use of brine is not recommended.

Vigorous agitation is necessary during the entire cooling process and slow agitation should be continued for several hours after cooling. Such practice further assists in completing mass crystallization that will prevent crystal growth and the development of coarseness after manufacture. The agitation should be of such a nature as to avoid excessive incorporation of air.

Temperature to Cool to.—The most suitable final temperature to which to cool the milk depends on the disposition of the condensed milk after manufacture. If the milk is to be filled in tins, a temperature of approximately 63° F. is usually the lowest at which this viscous product can be satisfactorily handled. If it is intended for the bulk trade for immediate use and is held in short storage at ordinary temperature before it leaves the factory, cooling to between 65° and 70° F. is sufficient. If it is intended for prolonged storage at low temperature (40° to 55° F.), cooling to 60° F. or below is preferable.

Effect of System of Cooling on Mass Crystallization.—The accomplishment of mass crystallization that prevents crystal growth and coarseness of texture after cooling varies considerably with the system of cooling used. In the case of the "Batch Cooling System," as described in succeeding paragraphs, the use of the intermediate or forced crystallization period and seeding is practically indispensable for dependable results. As previously stated, the temperature of maximum crystal growth varies with the lactose-in-water concentration. For sweetened condensed whole milk and sweetened condensed skimmilk made to comply with the United States' minimum standard for milk solids not fat, 86° F. is approximately the optimum temperature for seeding and for the beginning of the forced crystallization period. For sweetened condensed whole milk and skimmilk with much higher milk solids content, (such skimmilk with 28% milk solids for bakers' use), seeding at approximately 93° F. appears preferable. The examples given under "Determination of Temperature of Forced Crystallization," may serve to show to what extent the type or composition of product affects the theoretical optimum temperature of crystallization.

In the case of the "Continuous-Flow Cooling System," in which the condensed milk is cooled by passing under high pressure through a water-cooled coil, the use of the intermediate period appears superfluous. It is probable that the cooling milk comes into such intimate contact with the seed material, and the agitation is of such effective nature, that mass crystallization is almost instantaneous. But even here agitation after cooling is advisable for best results.

For more detailed information dealing with the science of milk sugar crystallization and the prevention of sandiness in sweetened condensed milk see Chapter XXIII on "Lactose Solubility," and Chapter XXV on "Sandy and Settled Sweetened Condensed Milk."

Determination of Temperature of Forced Crystallization.—As stated in previous paragraphs, the exact temperature of supersaturation of lactose, which determines the temperature of forced crystallization, varies with the lactose-in-water concentration of the condensed milk. The lactose concentration in turn depends on the type of condensed milk, whether made from whole milk, skimmilk or part skimmed milk, on the concentration of the solids not fat and on the per cent of sucrose or other added sugar.

In order to arrive at the approximately correct temperature of forced crystallization for condensed milk of widely varying compositions graph Fig. 48 has been prepared. The forced crystallization curve in this graph gives the temperature of forced crystallization on the basis of parts of lactose per 100 parts of water. The following concrete examples of condensed milk will explain how to use the chart.

The lactose content of the milk is usually not definitely known and facilities are generally lacking in the average factory to determine it quickly. The per cent lactose in the fluid milk (especially in the mixed milk) is quite constant. It is here estimated to be 4.8% for whole milk and 5% for skimmilk. Likewise, the per cent solids not fat in the fluid milk is estimated to be 8.5% for whole milk, 9% for skimmilk and 8.75% for half skimmed.

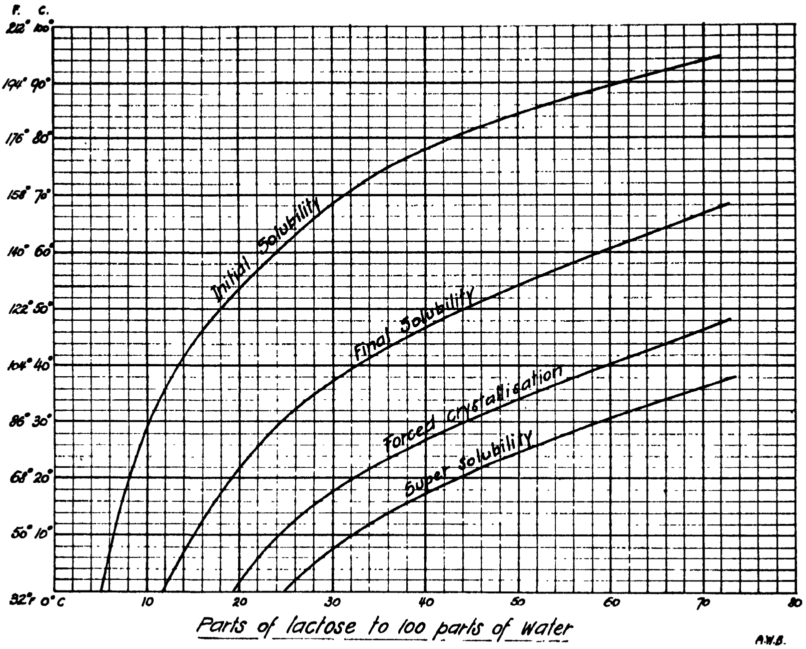

Fig. 48. Forced-crystallization chart

The per cent lactose in the condensed milk is calculated by multiplying the percent lactose of the fluid milk by the ratio of concentration. The ratio of concentration is calculated by dividing the per cent solids not fat in the condensed milk by the per cent solids not fat in the fluid milk.

Example 1.—Sweetened Condensed Whole Milk.—U. S. Standard.—

Condensed		Fluid	
Solids not fat	20%	Solids not fat	8.5%
Fat	8%	Lactose	4.8%
Sucrose	44%		
Water	28%		

Answer:

Ratio of concentration $\left(\frac{20}{8.5}\right) = 2.35$ to 1.

Per cent lactose in condensed milk $(4.8 \times 2.35) = 11.28\%$.

Parts lactose per 100 parts water $\left(\frac{11.28 \times 100}{28}\right) = 40.3$.

The "Forced Crystallization Curve" in the graph shows that the theoretically correct temperature at which this milk should be seeded is approximately 27.5° C. (81.5° F.).

Example 2.—Approximate Composition for Export Trade.

Condensed		Fluid	
Solids not fat	25. %	Solids not fat	8.5%
Fat	9.5%	Lactose	4.8%
Sucrose	40.5%		
Water	25. %		

Answer:

Ratio of concentration $\left(\frac{25}{8.5}\right) = 2.94$ to 1.

Per cent lactose in condensed milk $(4.8 \times 2.94) = 14.11\%$.

Parts lactose per 100 parts water $\left(\frac{14.11 \times 100}{25}\right) = 56.4$.

The "Forced Crystallization Curve" in the graph shows that the theoretically correct temperature at which this milk should be seeded is approximately 39° C. (102° F.).

Example 3.—Sweetened Condensed Skimmilk—U. S. Standard of Minimum Solids

Condensed		Fluid	
Milk solids	24%	Milk solids	9%
Sucrose	46%	Lactose	5%
Water	30%		

Answer:

Ratio of concentration $\left(\frac{24}{9}\right) = 2.67$ to 1.

Per cent lactose in condensed milk $(5 \times 2.67) = 13.35\%$.

Parts lactose per 100 parts water $\left(\frac{13.35}{30} \times 100\right) = 44.5$.

The "Forced Crystallization Curve" in the graph shows that the theoretically correct temperature at which this milk should be seeded is approximately 30° C. (86° F.).

Example 4.—Sweetened Condensed Skimmilk—High Milk Solids for Bakers' Use

Condensed		Fluid	
Milk solids	28. %	Milk solids	9%
Sucrose	43.5%	Lactose	5%
Water	28.5%		

Answer:

Ratio of concentration $\left(\frac{28}{9}\right) = 3.11$ to 1.

Per cent lactose in condensed milk $(5 \times 3.11) = 15.55\%$.

Parts lactose per 100 parts water $\left(\frac{15.55}{28.5} \times 100\right) = 54.5$.

The "Forced Crystallization Curve" in the graph shows that the theoretically correct temperature at which this milk should be seeded is approximately 37° C. (98.6° F.).

Example 5.—6% Fat Sweetened Condensed Milk—Preferred by Bakers and Confectioners

Condensed		Fluid	
Solids not fat	23.5%	Solids not fat	8.75%
Fat	6. %	Lactose	5. %
Sucrose	43.5%		
Water	27. %		

Answer:

Ratio of concentration $\left(\frac{23.5}{8.75}\right) = 2.68$ to 1.

Per cent lactose in condensed milk $(5 \times 2.68) = 13.40\%$.

Parts lactose per 100 parts water $\left(\frac{13.40}{27} \times 100\right) = 49.6$.

The "Forced Crystallization Curve" in the graph shows that the theoretically correct temperature at which this milk should be seeded is approximately 34° C. (93° F.).

Methods of Cooling Sweetened Condensed Milk.—The methods of cooling sweetened condensed milk that are in use are conveniently divided into two principal groups or systems, namely, the batch cooling system and the continuous-flow cooling system. Various types of equipment and methods of operation of each system are available.

The Batch Cooling System.—As the name implies, this system refers to cooling on the basis of batches or other units of limited size. The units are confined either to the ten-gallon milk can or other container of similar size, or to the coil vat or similar tank with agitator that circulates the cooling medium.

Cooling in Ten-Gallon Cans.—This is the oldest, most labor-consuming and mechanically the most primitive method. With suitable equipment and intelligent operation this system permits of satisfactory control of lactose crystallization and yields a product of smooth texture. It exposes the condensed milk to the atmosphere during the entire cooling process, however, and therefore invites bacterial contamination from the air unless special precautions are provided, such as the circulation of purified air through the cooling room, or the suspension of curtains of canvas or similar material above the tank containing the cans to exclude the factory air, or both. This method of cooling has been largely abandoned in American factories but is still widely used in European condenseries.

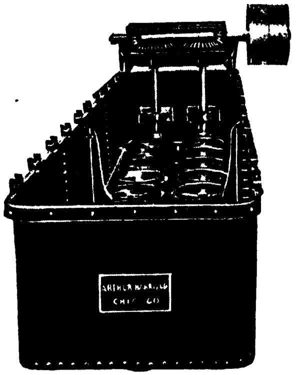

Fig. 49. Tank for cooling sweetened condensed milk in cans

Courtesy of Arthur Harris & Co.

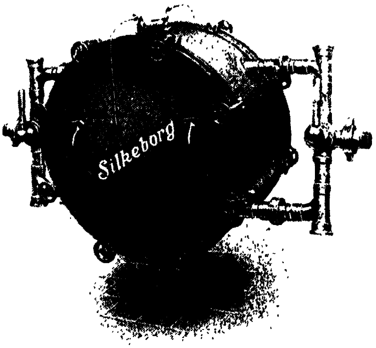

Fig. 50. Sweetened condensed milk strainer

Courtesy of Silkeborg Maskinfabrik

The equipment consists of a heavy iron tank, accommodating from 12 to 48 or more ten-gallon cans. The bottom of this tank is equipped with a system of interlocking cog-wheels. These wheels rest on stationary pivots projecting from the bottom of the tank. The diameter of the wheels is of the proper size to accommodate one can each and the entire system of wheels is set in motion by means of a gear with power transmission at one end of the tank.

The cans, filled with the hot condensed milk from the vacuum pan, are set on the cog-wheels in the tank. Suitable paddles for scraping the inside walls of the cans are inserted and fastened to cross-bars securely laid over the tank. The paddles are held stationary by the cross-bars and are forced against the periphery of the cans by springs. When in operation, the cans revolve and the milk is agitated by the stationary paddles.

In order for this equipment to operate satisfactorily, so that the agitation is uniform and the sides of the cans are scraped properly, the pivots in the bottom of the tank must be firm and true; the paddles must be straight-edged and held in such position as to scrape the entire side of the can from top to bottom; the cans must have straight walls free from indentations.

These cooling tanks are equipped with cold water distributing pipe and should have steam attachment for temperature control. If the milk is not to be seeded, it is best to start the cooling with water at a moderate temperature, 80° F., and then gradually admit cold water. When the temperature of the milk has been lowered to about 86° F., the temperature of the water should be so regulated as to cause the further cooling of the milk to 75° F. to occupy about 60 minutes. After that, the cooling may proceed as rapidly as the water facilities permit to the final cooling temperature.

If the milk is to be seeded with sugar crystals during the intermediate period, cold water may be used from the start. Seed material is added to the milk at the beginning of the intermediate period (86° F.). Add a teaspoonful of powdered milk sugar (about .5 oz.) or a small amount of condensed milk from a previous day's batch to each can. Take precautions to guard against contamination.

When the cooling is completed the paddles are removed, scraped and washed, and the cans are transferred to the filling machine.

Cooling in the Coil Vat.—Batch cooling of sweetened condensed milk by the use of the coil vat is proving a very practical method of cooling. It is particularly adapted to factories with limited volume, such as milk products plants in which sweetened condensed milk is a side line, and where its manufacture serves to provide a satisfactory outlet for surplus milk or skimmilk. The initial cost of the cooling equipment, the coil vat, is relatively small and often it is also used for other purposes in the factory. Its operation is simple and economical. It has the further advantage that the vat can be closed during operation, thus minimizing the danger of contamination from the surrounding air.

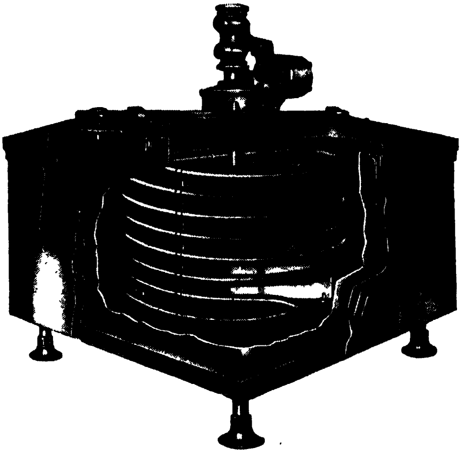

Fig. 51. Vertical coil vat cooler
Courtesy of Jensen Creamery Machinery Co.

The use of the coil vat for this purpose has gained rapidly in popularity since the establishment and more general understanding of the principles underlying the proper control of lactose crystallization. It lends itself advantageously to carrying out the forced crystallization plan in the form of seeding and retardation of the cooling at the desired temperature, as explained in preceding paragraphs under "Cooling" and "Determination of Temperature of Forced Crystallization," and in succeeding paragraphs under "Sweetened Condensed Skimmilk."

In the case of vats with two-speed coils, the higher speed should be used during the forced crystallization period. The vertical coil vat has the advantage of freedom from bearings and glands submerged in the milk. The fact that the movement of its coil tends in the direction of expelling rather than incorporating air, is of additional advantage.

In the operation of the horizontal coil vat air incorporation is materially minimized by adjusting the volume of milk to be cooled, so as to fill the vat sufficiently to cover the coil. A constriction in the lower portion in the vat, with the coil installed low in the restricted part, is of further assistance in keeping the coil covered and avoiding air incorporation.

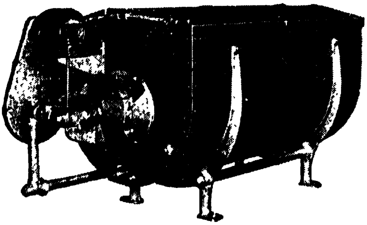

Fig. 52. Horizontal coil vat cooler

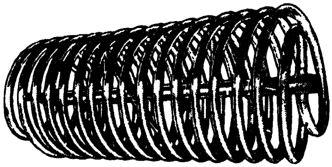

Fig. 53. Twin coil

Courtesy of Cherry-Burrell Corp.

The Continuous-Flow Cooling System.—In this system the cooling of the sweetened condensed milk is done by forcing the milk through tubes submerged in the cooling water. The earlier types of continuous-flow coolers consisted of tanks in which the tubes were submerged in slowly circulating, semi-stagnant, cooling water, with or without provision for a forced crystallization, retarding period. Concrete and iron tanks with submerged iron or copper coils and inlet and outlet for cooling water were used for this purpose. Representative types of this cooling system are the Mojonnier Submerged Coil Cooler and the Arthur Harris Submerged Coil Cooler.

Mojonnier Submerged Coil Cooler.—This equipment consists of a vertical tank, equipped with two sets of submerged coils. These coils have a diameter of about 1½ inches and a combined length of from 600 to 700 feet, the length needed depending on the temperature to which it is desired to cool the condensed milk and the temperature of the cooling water. The coil is preferably of regular, so-called sanitary pipe (copper pipe tinned on inside) though coils of black iron pipe are also in use. Such pipes should be sandblasted on the inside.

The submerged coil connects at its intake with a high pressure pump and at its outlet with one or more large enameled steel holding tanks. Each of these holding tanks is equipped with a powerful motor-driven, vertically slanting agitator, also enameled. The agitator revolves at a speed of about 12 R. P. M.

In the operation of this method of cooling, the hot sweetened condensed milk is drawn from the vacuum pan, preferably by gravity, into a standardizing vat, or drop tank, mounted on scales. When all the condensed milk of one and the same batch has been transferred to this tank, it is standardized to the desired percentage of total solids as directed in Chapter VIII.

From this standardizing tank the hot condensed milk is forced by means of a high pressure pump through the submerged coils in the cooling tank. The water supply to this tank is automatically regulated by a thermostat so set as to cool the condensed milk to the desired temperature (usually 75° F.).

In this cooling tank the condensed milk enters the outer coil at the bottom and returns through the inner coil with its outlet at the bottom. The intake of the cooling water is at the top and the outlet at the bottom. This arrangement does not provide the counter-current cooling principle and therefore does not permit of optimum uniformity of temperature reduction in the milk from intake to outlet. The cooling tank discharges the now cool condensed milk into the large holding tanks where it is slowly agitated for several hours.

The Arthur Harris Submerged Coil Cooler.—This cooler is of later design. It also has an inner and outer set of coil convolutions. In this case the two sets of coil are separated by a vertical baffle wall. The condensed milk enters the bottom of the inner coil and escapes at the bottom of the outer coil. The cooling water enters at the bottom of the outer compartment, flows over the top of the baffle and leaves the tank at the bottom of the inner compartment. The cooler thus functions on the counter-current principle, the cooling water entering the tank at the milk exit and leaving the tank at the milk intake. This provides a reasonably uniform cooling process, the warmest water contacting with hot milk and the coldest water contacting with the cooled milk.

The most outstanding disadvantage of all submerged coil coolers lies in the inaccessibility of their milk coils for cleaning, which renders them objectionable from the sanitary standpoint.

Internal Tube Counter-Current Coolers.—The latest and most improved continuous-flow coolers are of the internal tube type, either single milk tube or multiple milk tube, and the cooling water flows in counter-current to the milk. These coolers are equipped with removable return bend connections which permit of ready access for inspection and mechanical cleaning. They have the further advantage that they make possible uniform cooling, since the incoming hot milk meets the outgoing warmest water, thus making possible uniformly gradual cooling. The multiple milk tube coolers of the internal tube counter-current type are more efficient than the single milk tube coolers, because in the former the milk is exposed to more cooling surface. On the other hand, they have the disadvantage that they may not always cool uniformly. Especially when starting, the old milk may not push out of all the tubes simultaneously, thus building up back pressure and causing uneven release of the milk in the different tubes. In the single tube units the pressure is behind one tube only and the uniform passage of the milk through that tube is assured.

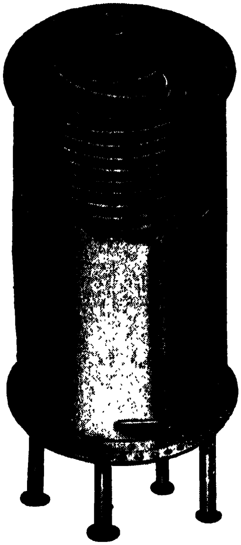

Fig. 54. Submerged coil continuous cooler
Courtesy of Arthur Harris & Co.

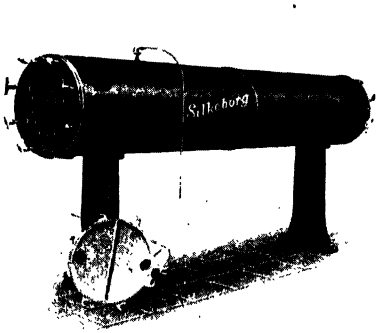

Fig. 55. Horizontal tube cooler
Courtesy of Silkeborg Maskinfabrik

The length of the tubes is chiefly determined by the number of cooling units, cooling capacity desired and available space. The thickness of the tubes must necessarily depend on their length, as the pressure increases with the total length of the cooling system. The thickness required for any given tube length likewise depends on the tensile strength of the metal used.

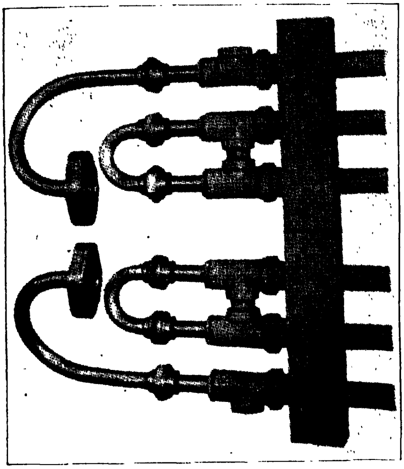

Fig. 56. Counter-current internal tube cooler
Courtesy of Arthur Harris & Co.

The tube thickness plays an important role in the efficiency of cooling. This applies especially in the case of tube metals of low heat transmission, such as steel and stainless steel. With thin wall-thickness the heat transmission of all metals is nearly the same. As the thickness increases, the ferrous metals become much less efficient than copper and copper alloys. For above reasons the advantage of greater cooling surface due to increase in length of cooling system is offset in part by the thicker tube wall and diminished heat transmission. However, the greater tensile strength of such metals as stainless steel permits of a thinner tube wall.

The most advanced design of condensed milk cooler is represented by the counter-current, high pressure, internal tube cooler with single milk tube of stainless steel and removable return bends. In these coolers the header discharges into two parallel counter-current cooling tubes and each section has its own water inlet and outlet. One high pressure milk pump may serve two sections. The total lineal tube length per section (about 70 feet), provides satisfactory speed and efficiency of cooling consistent with minimum pressure requirements. The temperature of the milk is controlled by regulation of the flow of cooling water. These cooling units no longer provide for a retarding period for forced crystallization, but they discharge the cooled milk into air-tight storage tanks (preferably glass-lined), which are equipped with a slowly moving impellor.

In operation, the vacuum pan is emptied into a drop tank from which the hot condensed milk is forced by means of a direct acting, high pressure milk pump through the internal tube cooler, using cold water as the cooling medium. The milk is cooled to approximately 60° F. and flows from the cooler into the evacuated storage tanks where it is slowly agitated under vacuum for about an hour.

After operation the milk tubes are not emptied, the condensed milk is left in them over night. The starting pressure is approximately 800 to 1,200 pounds, the running pressure from 200 to 300 pounds. Starting the old milk through and out of the cooler is facilitated and the pressure requirements minimized by preceding the cooling water with warm water.

Prolonged use of the cooler day after day without emptying and washing the tubes tends to build up a coating of sugar on the milk side of the tubes. This insulates them, diminishing heat transmission and retarding the cooling. It is advisable, therefore, to completely empty and clean the cooler at least once per week.

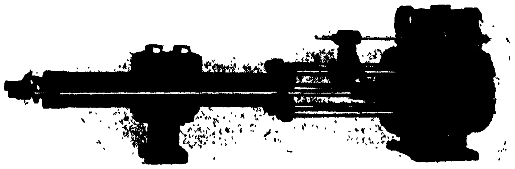

Fig. 57. High pressure milk pump
Courtesy of Arthur Harris & Co.

In this cooling system the cooling from pan temperature to the temperature desired is all done in one continuous operation. No retarding period is allowed for forced crystallization. However, the old milk in the tubes serves as the seeding material for the new condensed milk. In case the cooler has been completely emptied of its old milk the seed material is supplied by first pumping several gallons of old milk through the cooler.

This seeding of the new milk with old milk appears to supply the necessary condition for mass crystallization without special retardation of the cooling process. The sweetened condensed milk resulting from this system of cooling shows remarkably uniform smoothness and freedom from coarseness and sugar sediment.

The counter-current, high pressure, internal tube cooler system is particularly adapted for the cooling of large volume of sweetened condensed milk. This cooler is illustrated in Fig. 56.

The continuous-flow cooling system has the important advantage over the batch system in that in the former the cooling is done under complete exclusion of the atmosphere. This is true of both the submerged coil system and the internal tube system. Microbial contamination from exposure of the sweetened condensed milk to factory air during the cooling process jeopardizes its keeping quality and invites the development of such defects as buttons and gassy fermentation. When cooling by means of the continuous-flow system, the chief cause of these defects is greatly minimized if not entirely eliminated.

SWEETENED CONDENSED SKIMMILK

A considerable portion of the sweetened condensed milk output in this country goes in bulk to bakeries, confectioners and ice cream manufacturers. Much of the product for this trade is made from wholly or partly skimmed milk. A relatively large portion of this sweetened condensed skimmilk and part skimmilk is manufactured on a small scale by diverse milk products plants which are endeavoring to provide a satisfactory disposition for their surplus milk supply.

Owing to lack of experience and limitation of equipment, the operator not infrequently encounters serious difficulty in his efforts to satisfy his trade. His most common complaints usually are lack of a satisfactory body, and a coarse, gritty texture of his product with profuse sugar sediment in the bottom of the shipping can or barrel.

These defects may be readily avoided and a product highly satisfactory to the bakers' trade secured by paving attention to the following points:

1. The baker prefers a heavy viscous body. Low milk solids and high sugar content together with low temperature pasteurization yield a thin product that is not satisfactory.

While in the United States, the law permits of a minimum limit of 24% milk solids in sweetened condensed skimmilk, a more satisfactory product results when raising the milk solids to 28% and maintaining a ratio of milk solids to cane sugar of approximately 1:1.6. Assuming that the fluid skimmilk contains 9% milk solids, this ratio requires the addition of 14.5 pounds of cane sugar to every 100 pounds of skimmilk. Condense to a Baumé reading of approximately 36.5° B. at 120° F.

2. Preheat the skimmilk to a temperature not lower than 170° F. The temperature of preheating determines the body of the condensed milk and its tendency to thicken with age. The baker prefers a heavy body but he does not want the milk as solid as a custard. High temperature of preheating improves the body of the product while fresh, but increases the thickening tendency after manufacturing, if not stored in the cold.

If the product is disposed of soon after manufacture, preheat at 180° to 190° F. If it is intended for prolonged storage preheat at 170° F.

3. After condensing drop the batch into a coil vat and cool quickly to about 93° F. Retard the cooling for the next 60 minutes so that by the end of that time the temperature still is between about 75° to 80° F. At the beginning of this retardation period (93° F.), seed the milk with milk sugar crystals either by adding powdered milk sugar or condensed milk of a previous day's batch. Use four to five ounces of powdered milk sugar or two to three gallons of old sweetened condensed milk per 1,000 pounds (100 gallons) of condensed milk in the vat.

4. Agitate vigorously during this retardation period. In case of a two-speed coil use the higher speed. After the retardation period continue to cool to the final temperature as rapidly as facilities permit. Use cold water as the cooling medium. Do not use brine.

5. If the condensed milk is to be stored at room temperature, cool to 65° to 75° F. If it is to be cold stored, cool to 60° F. or below. Continue agitating for several hours after cooling. For prolonged storage store at 35° to 50° F. This will prevent objectionable thickening and development of buttons.

CHAPTER X

THE USE OF CORN SUGAR IN THE MANUFACTURE OF SWEETENED CONDENSED MILK

Advantages of Using Corn Sugar.—The economic advantages of substituting all or part of the sucrose (cane or beet sugar) in sweetened condensed milk with corn sugar (dextrose) have long been recognized. The attractiveness of such substitution has grown as the result of the development of processes and methods in the manufacture of cornstarch products that made commercially available a product—refined dextrose—of a high standard of purity and quality. The lesser sweetness, superior properties of assimilation and the possibility of greater preserving power that would decrease the proportion of sugar needed and thereby yield a better balanced finished product, are fully recognized as additional factors in favor of the use of dextrose.

These considerations of the possibilities of substituting dextrose for sucrose in sweetened condensed milk received a new impetus in this country by a ruling of the Secretary of the United States Department of Agriculture,[43] issued December 26, 1930, to the effect that "the use of pure refined corn sugar as an ingredient in the packing, preparation or processing of any article of food in which sugar is a recognized element, need not be declared upon the label of any such product."

Effect of Dextrose on Marketable Properties of Sweetened Condensed Milk.—The possibilities of using refined corn sugar in the manufacture of sweetened condensed milk were experimentally studied by Rogers,[44] Hunziker,[45] and Ramsey, Tracy and Ruehe.[46] Rogers and Hunziker experimented with whole milk both from the standpoint of substituting different portions of the sucrose with dextrose, and of modifying the composition of sweetened condensed milk in such a manner and to such an extent as to confine the added sugar to dextrose only. Ramsey, Tracy and Ruehe's investigation had to do with sweetened condensed skimmilk in which a portion of the sucrose was substituted by dextrose. The principal problems involved in preserving the marketable properties of sweetened condensed milk that contains dextrose are the abnormal tendency of the finished product to thicken, to darken in color, and to suffer mass crystallization of the corn sugar during storage. Our present knowledge on this subject shows that the development of these defects can be avoided wholly or in part by certain modifications in the process of manufacture, as explained briefly in succeeding paragraphs. For details on chemistry, crystal-formation and physical properties see Chapter XXIII.

The Preserving Power of Dextrose.—According to the science of biology the preserving power of a substance in solution depends on its osmotic pressure. This is the pressure created when a solution of a certain concentration is separated from a solution of lesser or greater concentration by a membrane.

The bacterial cell has a membrane surrounding the protoplasm inside of the cell wall. The only means for food to get into the cell is by diffusion or osmosis through the cell membrane. If the cell is submerged in a strong solution of a substance which cannot pass through the membrane, this substance will cause an osmotic pressure. The concentration of the solution in the cell being lower than that of the surrounding solution, the law of equalization will cause the water to pass from the inside of the cell through the membrane (exosmosis) until the concentration inside and outside of the cell membrane is the same. The loss of water causes the shrinking of the protoplasm and the caving-in of the membrane, while the rigid cell wall retains the outward shape of the cell. This dehydration of the cell diminishes its vitality, inhibits its growth and may lead to the death of the cell.

The resistance of various microorganisms to the destructive or inhibitive effect of the osmotic pressure of concentrated solutions depends upon the type of organism as well as upon the kind, concentration and temperature of the dissolved substance.

The osmotic pressure of a substance increases in direct ratio to the number of its molecules in solution. Solutions of the same number of molecules have the same osmotic pressure. Hence a given concentration of a compound with large molecules, such as sucrose ($C_{12}O_{22}H_{11}$) for instance, will produce a lower osmotic pressure than a similar concentration of a compound with molecules of smaller molecular weight, such as dextrose ($C_6H_{12}O_6H_2O.$).

Theoretically, therefore, the ratio of osmotic pressure between sucrose and dextrose is determined by their relative molecular weights. This ratio is 198 to 342 or 1 to 1.73. Theoretically the osmotic pressure of dextrose is nearly twice (1.73 times) as great as that of sucrose. On the basis of its calculated osmotic pressure dextrose should be approximately 1¾ times as effective in preserving condensed milk as sucrose.

Unfortunately, available experimental data on determinations of the osmotic pressure of these sugars in aqueous solution and in sweetened condensed skimmilk show wide deviations from the corresponding calculated osmotic pressures. Berkeley and Hortley[47] show that as the concentration is increased the osmotic pressure of sucrose gradually approaches that of dextrose; and Frazier and Myrick[48] found the osmotic pressure in sweetened condensed skimmilk to be almost four times its theoretical osmotic pressure in an ideal solution.

Ramsey and co-workers tested the relative preserving power of the two sugars in various concentrations in plain broth solutions inoculated with a large spore-forming rod isolated from sweetened condensed milk, and concluded that "at low concentrations sucrose may exert more preserving power than dextrose and at high concentrations dextrose and sucrose may have approximately the same preserving power." Hunziker concluded that his experimental results suggest that the preserving effect of dextrose in sweetened condensed milk is approximately 1.25 to 1.33 times as great as that of sucrose.

There is need of further confirmation of these results and conclusions by more extended study in order to justify their acceptance as a safe basis for use in commercial manufacture. The available results do give reasonable assurance, however, that from the standpoint of its preservative power, dextrose is not unsuitable for use in the manufacture of sweetened condensed milk.

Effect of Dextrose on Thickening Tendency of Sweetened Condensed Milk.—The tendency of sweetened condensed milk to suffer progressive thickening during storage is vastly increased in the presence of dextrose. Rogers, Hunziker and Ramsey and co-workers found this progressive thickening to be one of the outstanding defects of sweetened condensed milk containing dextrose. This progressive thickening after manufacture occurred particularly when the dextrose was added to the fluid milk and was forewarmed with it. When dissolving the dextrose in heated water and drawing this dextrose syrup into the pan toward the end of the condensing process, abnormal thickening other than that usually caused by the use of high forewarming temperature and high storage temperature of the finished product, was absent.

Absence of developed acidity and the general character of the thickened product strongly suggest that the thickening is confined to physical thickening and is not caused by bacterial thickening. Ramsey and co-workers found this physical thickening to be due to the effect of the dextrose on the stability of the casein and albumin, especially the former, the nature of the reaction suggesting an amino-aldehyde condensation. When proteins or skimmilk were heated with dextrose there was a marked change in the physical nature of the casein. The casein lost most of its Biuret reaction, showing that its peptide linkage in the protein molecule had been sacrificed in the casein-dextrose reaction; the casein gave a strong reducing test with Benedict's solution indicating the presence of reducing sugars such as dextrose. Further evidence emphasizing the changed nature of the casein was the fact that it was difficult if not impossible to precipitate the proteins with acids and rennet; the curd formed with rennet and calcium chloride was very soft and flocculent; and the addition of mineral salts hastened coagulation.

It appears resonable to assume, therefore, that the abnormal thickening tendency of sweetened condensed milk containing dextrose is fundamentally due to the peculiar action of the dextrose on the casein, forming a protein-dextrose complex and causing the physical nature and behavior of the casein to be changed. It is possible that the casein in the casein-dextrose complex is of a nature more susceptible to hydration, causing progressive swelling of the casein.

Or, the reaction brought about by heating the milk in the presence of dextrose may cause a deficiency of calcium in the calcium-casein balance, either by replacing a part of the calcium in the calcium-casein molecule, or by reacting direct with the calcium or other mineral salts. In either case a deficiency of calcium might result because of the relatively large amount of dextrose present, and this calcium deficiency would tend to unstabilize the casein, lower the heat coagulation point and encourage progressive thickening.

Since the reaction between the proteins and dextrose is greatly intensified in the presence of heat, the thickening tendency of sweetened condensed milk containing dextrose can be largely avoided, as far as the effect of the dextrose is concerned, by dissolving the dextrose in water, forewarming the fluid milk and the dextrose syrup separately, and drawing the latter into the vacuum pan toward the end of the condensing process.

Effect of Dextrose on Color of Sweetened Condensed Milk.—All available data on results of experiments in which dextrose has been used in the preparation of sweetened condensed milk show that the finished product suffered an objectionable brown discoloration, while similar products containing sucrose in the place of dextrose retain their natural color except upon prolonged storage at high temperature.

The browning of the condensed milk, both sweetened and unsweetened, has been long and consistently attributed to caramelization of the sugar (especially the lactose) in the presence of the heat treatment during manufacture. This assumption has persisted in spite of the fact that numerous investigators observed that the proteins in milk and other dairy products so discolored also showed a brownish color.

It is the recent work of Ramsey and Ramsey, Tracy and Ruehe, however, that shows unmistakably that the brown discoloration of sweetened condensed milk and probably also of evaporated milk is not due to caramelization of the sugar contained in these products, but is caused by reactions of the sugar with the proteins of milk that involve the formation of certain sugar-protein condensation products. These investigators demonstrated that water solutions of sucrose, dextrose and lactose, respectively, when heated for 30 minutes to 250° F. showed no signs of discoloration. Likewise, distilled water emulsions of albumin and casein when similarly heated failed to darken.

But when milk, albumin or casein were heated with lactose or dextrose a marked brown coloration resulted. Examination of the proteins and whey from dark-brown sweetened condensed milk showed the precipitated proteins to be very brown in color while the whey showed no evidence of caramel color. The discoloration was most intense in the presence of dextrose. It was intense also in the case of lactose while with sucrose it was negligible. These results are in harmony with earlier observations of the coloration of the proteins in milk upon heating by Leeds,[50] Hunziker and Hosman,[4] and Hunziker.[51]

It appears that in the sugar-protein reaction responsible for the darkening of the proteins certain amino acids are involved. The sugar combines with the NH_2 group which is alkaline, neutralizing the alkalinity and leaving the acid group free, thereby lowering the pH. It is well known that sugar heated with an alkali turns brown, hence the amino acid—sugar group which is alkaline would tend to assume a dark color. This would be the case especially with a reducing sugar such as dextrose or lactose, because of the availability of the aldehyde or ketone groups which are naturally present in these sugars.

In the case of sucrose, on the other hand, no condensation product would result because in the sucrose molecule a very stable linkage of the aldehyde group of dextrose and the ketone group of fructose or levulose exists. The possibility of sucrose entering into the sugar amino acid complex would be confined to cases of inversion of the sucrose forming dextrose and levulose.

Haradine,[49] studied the effect of the addition of invert syrup to sweetened condensed milk on the color of the milk held in storage, and concludes that when less than 25 per cent of the sucrose is substituted with invert syrup, the change in color progresses at approximately the same rate as in the absence of invert syrup, but that when such substitution exceeds 25 per cent, the brown discoloration is very noticeably hastened.

Sucrose inversion in sweetened condensed milk might occur by exposure to heat in the presence of relatively high acidity or by the action of certain enzymes. The inversion of as much as 25 per cent of the sucrose present, however, is highly improbable in condensed milk manufactured and stored under usual and normal conditions. Assuming that Haradine's conclusions of the proportion of inversion required to cause darkening in color are correct, it appears improbable, theoretically at least, for sucrose to be the usual cause of discoloration.

Englis and Dykins[52] further show that the sugar-protein reaction is intensified by decreasing the hydrogen ion concentration. The brown coloration of condensed milk, likewise, becomes more pronounced in the presence of an alkali such as may be introduced by the use of waters containing basic carbonates, for dissolving the sugar. This was demonstrated by Ramsey and co-workers who dissolved dextrose in hard water and observed a marked brownish discoloration of both the dextrose syrup and the condensed milk containing it.

The above discussion shows definitely that the brown discoloration observed in sweetened condensed milk containing dextrose is not due to direct caramelization of the sugar nor to inversion of the sucrose, but is caused by reactions between sugar and amino acid groups of the milk proteins, and that the sugar-protein complexes so formed, themselves exhibit a brown coloration which is responsible for the brown color of the condensed milk. The readiness with which this reaction and the resulting discoloration takes place is attributed to the fact that dextrose contains free aldehyde groups which are relatively very active. This reaction is greatly intensified by heat and in the presence of alkalies.

In order, therefore, to avoid the brown discoloration of sweetened condensed milk in the manufacture of which corn sugar is used, the dextrose should not be dissolved in the fluid milk at the time of forewarming. It should be dissolved in a small amount of water, making about a 65% sugar solution. The milk and the sugar syrup should be forewarmed separately and the sugar syrup should be drawn into the vacuum pan toward the end of the condensing process. The water used for dissolving the dextrose should be free from alkalies such as basic carbonates. In the case of hard water it is advisable to add a small amount of hydrochloric or acetic acid reducing the pH to approximately 6.8 or to a Brom-thymol-blue. For directions for making the Brom-thymol-blue test see Chapter XXXVII.

It is important, further, as shown by Ramsey and co-workers, that the equipment in which the sugar syrup is prepared be free from remnants of milk and from milk stone. The presence of either will darken the hot dextrose solution. See also Chapter XXIII under "The Color of Milk."

Effect of Dextrose on Sugar Crystallization in Sweetened Condensed Milk.—Dextrose is less soluble than sucrose. The difference in solubility between the two sugars is especially marked at the lower temperatures, as shown in Table 12, which indicates the solubility of dextrose[53] and sucrose[54] in aqueous solutions at different temperatures.

Table 12.—Solubility of Dextrose and Sucrose

Temperature		Per Cent Sugar in Water Solutions	
° C.	° F.	Dextrose By Jackson & Silsbee (53)	Sucrose By Brown (54)
0	32	35.0	64.18
10	50	40.8	65.58
15	59	44.0	66.30
20	68	47.2	67.09
25	77	50.8	67.89
30	86	54.64	68.70
35	95	58.02	69.55
40	104	61.87	70.42
45	113	65.71	71.32
50	122	70.91	72.25

Because of the relatively low solubility of dextrose at low temperatures the occurence of mass crystallization during storage of sweetened condensed milk containing dextrose presents a serious difficulty and places certain limits on the amount of dextrose that may be used in this product without danger of disastrous mass crystallization after manufacture. Ramsey and co-workers show that sweetened condensed skimmilk containing 27.3 per cent dextrose (the dextrose-in-water concentration was 37.9%) when stored at 40° F. remained smooth after 90 days. When the dextrose content in the condensed milk was increased to 31.85 per cent (the dextrose-in-water concentration was 44.3%) mass crystallization set in after 75 days at 40° F. These results are in general agreement with the dextrose in water solubility figures shown in Table 12.

However, Ramsey et al further show that sweetened condensed skimmilk containing 27.3% dextrose and 12% sucrose also remained smooth after 90 days storage at 40° F. This product had a total sugar-in-water concentration of 54.5% and the dextrose-in-water concentration was 44.75%. The solubility of the dextrose in this case exceeded that where dextrose only was used in the condensed milk and it greatly exceeds the dextrose solubility figures given by Jackson and Silsbee as shown in Table 12.

Ramsey and co-workers found it advisable to replace only part of the sucrose by dextrose. While they concluded that it was possible to replace approximately 75% of the sucrose with corn sugar without danger of crystallization after 130 hours at 40° F., they recommend to replace only 50% of the sucrose with corn sugar, using half cane sugar and half corn sugar.

Ramsey's results and conclusions agree in general with those of Hunziker, who used whole milk and whose storage temperatures were 55° F., and 75 to 80° F., respectively. Replacing 75% of the sucrose with an equal amount of dextrose, however, did not prevent mass crystallization at the lower storage temperature in every case, nor did it appear necessary to replace the sucrose by an equal amount of dextrose to prevent deterioration due to bacterial causes. This observation led to trials with diverse combinations of the two sugars, milk solids and water, and it was found that lowering the total sugar content to 36 per cent of which one-third (12 per cent) was sucrose and two-thirds (24 per cent) was dextrose, and raising the milk solids to 33 per cent and the water to 31 per cent, yielded an apparently satisfactory product that held its dextrose in solution, that developed no mass crystallization after 60 days at 55° F. and that showed no bacterial deterioration during 60 days storage at 75 to 80° F.

Attempts to replace all sucrose with dextrose, using dextrose only, have not been sufficiently extensive, however, to justify this practice on a commercial scale without further trials. Replacing all of the sucrose with an equal amount of dextrose is out of the question on account of inevitable mass crystallization at practically any storage temperature. A fairly good product when using dextrose only results by reducing the amount of sugar to approximately 30.5 per cent and raising the milk solids and the water to approximately 35 per cent and 34.5 per cent, respectively. While a product of this composition developed no noticeable bacterial defects and did not develop mass crystallization in storage, its dextrose-in-water concentration is so high (46.9%) that it is doubtful that the dextrose would stay in solution at the lower storage temperatures. On the other hand, a materially lower dextrose-in-water concentration could not be expected to provide sufficient preserving power to avoid bacterial deterioration.

Effect of Dextrose on Flavor of Sweetened Condensed Milk.—The presence of corn sugar in the place of all or part of the cane sugar alters the flavor of the sweetened condensed milk. There is no denying that the flavor is different from the accustomed sweetness of sweetened condensed milk that contains sucrose only.

The use of dextrose in the manufacture of bakery products, confections, candy, and ice cream is not new. Aside from the advantage of economy, dextrose has properties which have proven advantageous in their effect upon the quality of some of these products. In the case of bakery goods experiments by Morrison and Gerber[55] at the American Institute of Baking showed that the substitution of dextrose for the sucrose in the batter yielded no noticeable difference. The product containing dextrose, however, received a score 2.5 points higher due to a slightly improved grain, color of crumb, and texture. In the manufacture of ice cream dextrose has been successfully used at least to a limited extent. Occasionally sweetened condensed skimmilk is used to bring up the milk solids in the mix. It appears reasonable to assume, therefore, that sweetened condensed skimmilk containing a limited amount of dextrose would not be objected to by the ice cream manufacturer. In some instances the ice cream manufacturer, in fact, insists on the use of dextrose in sweetened condensed milk. The candy manufacturer likewise is using dextrose to good advantage and its presence in the sweetened condensed milk he uses should cause no serious objections.

In the case of sweetened condensed milk packed in the consumer's package—the tin—long usage has established the flavor of condensed milk sweetened exclusively with sucrose so firmly on the palate of the consumer that he may show considerable reluctance in accepting a product sweetened wholly or in part with dextrose. Likewise, the range of the conditions to which the product is exposed between factory and consumer's table may far exceed the extremes that were imposed upon the experimental batches made, thus exhausting the margin of safety on keeping quality and prevention of mass crystallization. These several uncertainties suggest the advisability of further and more extensive experimental study before embarking upon the "wholesale" filling of tins with condensed milk in which all or a considerable portion of the sucrose has been substituted with dextrose.

POSSIBILITIES AND LIMITATIONS OF USE OF CORN SUGAR IN COMMERCIAL MANUFACTURE OF SWEETENED CONDENSED MILK

The foregoing discussion of the properties of corn sugar leaves no doubt of the suitableness of dextrose as a component of sweetened condensed milk, provided that its use is so adjusted as to preserve the marketable properties of the finished product and to conform to the demands of the market for which the latter is intended. These requirements may be briefly summarized as follows:

1. **Flavor of Sweeetened Condensed Milk.**—Dextrose imparts to sweetened condensed milk a flavor somewhat different from that of condensed milk sweetened with sucrose only. This flavor is not objectionable but it is different. The larger the portion of sucrose that is substituted with dextrose the more pronounced is the difference in flavor. It has been shown that where sweetened condensed milk is intended for use in the bakery, confectionery, candy factory, and ice cream factory this dextrose character not only has proven acceptable but has in addition revealed some distinct physical advantages. In the case of canned goods caution suggests the advisability of further investigation before attempting the general introduction of dextrose in their manufacture.

2. **Thickening and Discoloration.**—It has been shown in previous paragraphs that the presence of dextrose in sweetened condensed milk greatly increases the tendency of the finished product to thicken and develop a brown coloration in storage. Our present knowledge of the causes of these defects is sufficient to prevent their appearance by the proper modification of the

process of manufacture. The use of dextrose is, therefore, no longer objectionable from the standpoint of danger of thickening and darkening of the finished product.

3. **Keeping Quality and Sugar Crystallization.**—Because of the relatively low solubility of dextrose the amount of dextrose which sweetened condensed milk may contain without danger of objectionable mass crystallization at low storage temperatures is far more limited than is the amount of sucrose. The problem, therefore, lies in having the dextrose-in-water concentration low enough to hold the dextrose in permanent solution and at the same time to have the sugar-in-water concentration high enough to insure dependable preserving power and keeping quality.

Formula for Use of Dextrose.—The available experimental results suggest three alternatives of formula or composition of the finished product in which part or all of the sucrose is substituted with dextrose. Their relative merits from the standpoint of freedom from danger of objectionable mass crystallization and of insuring sufficient preservative strength of their sugar concentrations to prevent damaging bacterial deterioration are briefly stated under each formula:

Formula No. 1.

Composition of Finished Product

Milk Solids		28%
Sugar	sucrose 21% dextrose 21%	42%
Water		30%
Total		100%

Sweetened condensed skimmilk containing 28 per cent milk solids and 42 per cent sugar is a highly satisfactory product for the use of the baker who desires an all skim product. In the above formula one-half of the sucrose is substituted with an equal amount of dextrose. The total sugar-in-water concentration is $\frac{42}{42 + 30} = 58.33\%$. This is sufficient to insure satisfactory keeping quality under the usual conditions of handling sweetened condensed milk in bulk. The dextrose-in-water concentration is $\frac{21}{21+30} = 41.17\%$. This is low enough to keep the dextrose in solution and prevent objectionable mass crystallization during storage.

Formula No. 2.

Composition of Finished Product

Milk Solids		33%
Sugar	sucrose 12% dextrose 24%	36%
Water		31%
Total		100%

In this formula the total sugar is 36 per cent, of which one-third is sucrose and two-thirds dextrose. The total sugar-in-water concentration is $\frac{36}{36+31} = 52.69$ per cent. This relatively low total sugar-in-water concentration is compensated for by the large proportion of dextrose which has a sufficiently higher preserving power to insure freedom from bacterial deterioration. The dextrose-in-water concentration is $\frac{24}{24+31} =$ 43.63 per cent. This dextrose concentration still is low enough to avoid objectionable mass crystallization during storage. While experimental results substantiate these facts as to the excellent quality of the finished product, the fact should not be overlooked that the margin of safety both as to keeping quality and of holding the sugar in permanent solution, here is smaller than in the case of formula No. 1. On the other hand this formula makes more liberal use of dextrose and effects a decisive reduction in the cost of manufacture by substituting a large portion of the sucrose which is the most expensive item, with dextrose, milk solids and water. The experimental batches made according to this formula consisted of whole milk, the finished product containing approximately 8.5 per cent fat and 24.5 per cent of milk solids not fat. The milk remained perfectly smooth after 60 days at 55° F. and showed no signs of flavor deterioration and no fermentation defects after 60 days at 75° to 80° F.

Formula No. 3.

Composition of Finished Product	
Milk Solids	35. %
Dextrose	30.5%
Water	34.5%
Total	100.0%

In this formula the added sugar is confined to dextrose only. The ratio of dextrose to water was made as high as possible consistent with avoidance of mass crystallization. The dextrose-in-water concentration is $\frac{30.5}{30.5 + 34.5} = 46.90\%$. Theoretically this dextrose concentration will stay in solution at room temperature, but not at low storage temperatures. Yet this milk did not develop mass crystallization after 60 days at 55° F. Likewise it showed no visible signs of bacterial or flavor deterioration after 60 days at 75° to 80° F. From the standpoint of cost of manufacture this formula obviously is by far the cheapest and yet it offers the consumer a similar ratio of milk solids to water as is contained in the standard product that is sweetened with sucrose only. Containing a higher percentage of milk solids and a much lower percentage of sugar, it constitutes a better balanced food. Its freedom from mass crystallization and bacterial deterioration with age, however, has not been established under a sufficiently wide range of storage conditions. More extensive trials are needed to establish the dependability of its marketable properties and to justify the use of this formula on a commercial scale.

Factory Directions for Use of Dextrose in the Manufacture of Sweetened Condensed Milk.—For the convenience of the factory operator the different steps in the manufacture of sweetened condensed milk in which a portion of the sucrose is substituted by dextrose are briefly outlined. For this example, formula No. 1 is used but a similar procedure is recommended for other formulas in which dextrose is used.

Composition of Finished Product According to Formula No. 1.—The sweetened condensed skimmilk is to contain 28 per cent milk solids and 42 per cent added sugar consisting of half sucrose and half dextrose. The amount of fluid skimmilk to be condensed is 6,000 pounds, testing 9 per cent solids.

Calculation of Amount of Sugar.—The ratio of milk solids to total sugar in the finished product is 28 to 42. The amount of sugar needed for a batch of 6,000 pounds of skimmilk testing 9 per cent milk solids therefore is:

$$\frac{6000 \times .09}{28} \times 42 = 810 \text{ pounds of sugar needed.}$$

Weigh out one-half of this amount, or 405 pounds of each, sucrose and dextrose.

Forewarming the Milk.—Heat the milk to 165° F. or higher and hold as follows:

When forewarming to 165° F. hold 15 minutes
" " " 170° F. " 10 "
" " " 175° F. " 5 "

At 180° F. or above no holding is necessary.

The choice of forewarming temperature should be governed by the time and condition of subsequent storage of the finished product. The higher temperatures of forewarming yield a better body but the tendency of progressive thickening in storage is increased. If the product is used soon after manufacture or is stored at low temperature (40° to 50° F.) the higher forewarming temperatures are recommended. If the product is stored at ordinary temperature forewarming at 165° to 170° F. is preferable.

Addition of the Sugar.—Do not add the sugar to the milk in the forewarmer. Draw the heated milk into the vacuum pan and add the sugar dissolved in water toward the end of the condensing process.

Dissolve the 810 pounds of half sucrose and half dextrose in enough water to make a concentrated solution (about 65 per cent). Heat to about 180° F. and draw this hot sugar syrup into the pan.

The kettle in which the sugar syrup is prepared should be completely free from remnants of milk and from milk stone and the water used for dissolving the sugar should contain no free alkali. If the water contains free OH-ions, such as is the case with many hard waters, acidify it by the addition of a weak acid such as acetic, to Brom-thymol-blue (for method see Chapter XXXVII).

Concentration.—Condense to the desired point of concentration. Condensed skimmilk containing 28 per cent milk solids and 42 per cent added sugar shows a Baumé reading at 120° F. of 34.2° B.

Cooling.—When the above concentration has been attained drop the batch into a coil vat or other condensed milk cooler and cool rapidly to 90° F. Now seed the milk by adding 4 ounces of powdered milk sugar or two gallons of sweetened condensed milk from a previous day's batch, per 1,000 pounds of condensed milk, distributing the seed material well over the milk in the cooling vat. Continue agitating vigorously (if a coil vat with two speeds use the higher speed) for an hour, without lowering the temperature below 75° F. Then finish the cooling to storage temperature and continue agitating for several more hours (overnight if facilities permit).

Storing.—Store at as low a temperature as practical. For prolonged storage a temperature of 40° to 50° F. is preferable to higher temperatures. Low temperature storage greatly retards both progressive thickening and discoloration.

CHAPTER XI.

PACKING SWEETENED CONDENSED MILK FOR MARKET

The sweetened condensed milk reaches the market in milk shipping cans, barrels and in hermetically sealed tin cans.

Packing in Barrels.—Barrels similar to glucose barrels are used. They hold from 300 to 700 pounds of condensed milk. It is wise to use new barrels. Old glucose barrels are difficult to put in satisfactory, sanitary condition. Remnants of glucose in them invite fermentation, and mold spores in the pores of the wood may cause the development of "buttons" in the condensed milk. The re-use of old condensed milk barrels involves similar risks. The paraffining, or coating with sodium silicate, of the inside of barrels assists in minimizing the danger of the barrel as a source of damaging contamination.

Before filling the new barrels they are steamed thoroughly and drained. They are filled through the bunghole by the use of a suitable funnel. A convenient funnel is provided by the use of an ordinary milk pail with a nipple one and a half inches in diameter in the bottom. After filling, a double layer of cheese cloth is placed over the bunghole and the bung is driven in level with the staves.

Packing in Cans.—The canned goods are intended for the retail market. The cans used hold from eight ounces to one gallon of condensed milk. Most makes of tin cans for sweetened condensed milk have a small opening, three-eighths to three-fourths inch in diameter through which they are filled. The cans known and sold under the trade name "sanitary can" are filled before the top end is crimped on. Sweetened condensed milk is of a semi-fluid, viscous and sticky consistency. The successful and rapid filling of the cans without spilling the milk over the top of the can is, therefore, somewhat difficult. If done by hand the work is very slow. Several ingenious filling machines have been devised which are more or less efficient in "cutting off" the milk without "slobbering." The filling machines now in use vary from the primitive hand filler, in which the condensed milk is "ground out" by the turning of a crank by hand, to the most perfect forms of automatic filling machines. They usually are equipped with a reservoir, receiving tank or hopper, which has an automatic feed, usually a float-valve arrangement, that regulates the inflow according to the discharge. The discharge is adjustable to fill any size can with a remarkable degree of accuracy, except gallons which are usually filled by hand. Machines of this type will fill from twenty-five thousand to thirty thousand cans per day (ten hours).

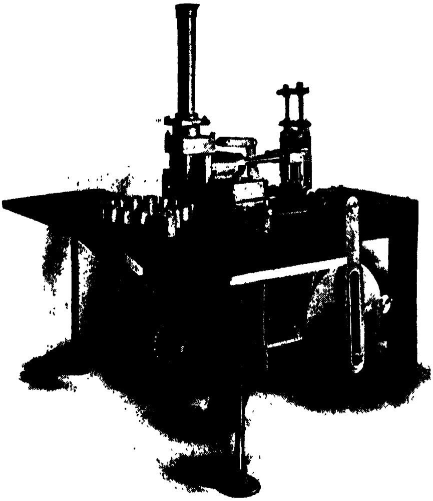

Fig. 58. Berlin sweetened condensed milk filler
Courtesy of Berlin Chapman Co.

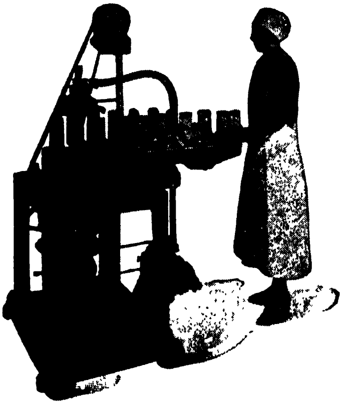

Fig. 59. Kiefer sweetened condensed milk filler
Courtesy of The Kiefer Filling Machine Co.

These machines are of complex construction and must receive proper care. It is best to clean them thoroughly after each day's work. But, since their inlet and discharge are closed hermetically, the complete washing may be done once per week only, without seriously disturbing their efficiency or impairing the product. For thorough cleaning, the filler should be dissected, removing all detachable parts, such as valves, pistons, tubes, etc. When freed from all remnants of condensed milk, the parts should be scalded, dried and replaced in the machine. In order to guard against all possible contamination by remnants of wash water, it is advisable to reject the first few cans of milk of the next filling. When not in use, the filling machine should be covered with a clean cloth, or oil cloth, to protect it from dust and flies, etc.

As soon as the cans are filled, they should be "capped." If allowed to stand open, dust, dirt and flies or other insects are prone to reach their interior, and the prolonged exposure of the condensed milk to air and light causes the surface to crust over and to develop a tallowy flavor.

SEALING THE TINS

Kinds of Seals.—The seal must be air-tight and firm enough to prevent its breaking during the rough treatment to which the cans are exposed in transportation. There are several methods of sealing the cans, depending largely on the type of seal. Most of the cans used are sealed with solder. There is a groove around the opening, into which the periphery of the cap fits and

Fig. 60. The solder seal

Fig. 61. The sanitary can

Fig. 62. The Gebee seal

Fig. 63. The McDonald seal

which is then filled with solder. In the case of cans which are sealed without solder, the cap or the entire end of the can is crimped onto the can so as to make a hermetical seal. The McDonald seal with the friction cap, the Gebee seal with the burr cap, and the Sanitary can seal with the top of the can crimped on after filling, are the chief types of solderless seals. In the case of the McDonald seal, a tightly fitting cap with a wide flange is pressed into the opening. The "capped" can passes under a series of steel rollers pressing the flange firmly against the top of the can. This seal is very simple, but is not very strong and not hermetically tight. In the case of the Gebee seal, a vertical rim projects around the opening of the can. After the cap is inserted, it is crimped over this rim by means of a series of revolving dies. This seal is reasonably strong but not hermetically tight. The Sanitary can is entirely open at one end when filled. The cover or end is crimped around the periphery of the body of the can by means of revolving dies. This seal is reasonably strong and usually hermetically tight. The chief advantages of the seals without solder lie in the saving of labor and eliminating the cost of the solder.

Soldering Devices and Machinery.—The sealing of all solderless seals is done by specially constructed sealing machines.

For seals with solder there are several machines on the market but some of this work is as yet done by hand. For this, different types of soldering coppers are in use, the copper tips are heated in soldering stoves or pots, or the soldering coppers themselves are equipped with gas or electric attachment for automatic heating.

Ordinary soldering coppers with a blunt point, such as are in general use by the tinsmith, are not satisfactory. Unless they are drawn out and filed down to a fine point, their use is not conducive of neat work, progress is comparatively slow and leakers are often numerous. When gas is available the automatic soldering copper may be used to advantage. In this tool the copper tip, which is long and slender, is automatically heated by a current of gas passing through the handle and burning at the copper tip. The handle of the device is connected with the gas and air pipes by means of flexible rubber tubing. No time is lost waiting for the copper to heat and the flame can be so regulated that the temperature of the copper tip is right and uniform. This is important, because perfect work is impossible unless the coppers have the proper temperature. Electric soldering coppers are also in use for the same purpose.

Machine-soldering is now rapidly replacing hand-soldering. The newer types of can soldering machines do very efficient and neat work and their operation in factories with large outputs economizes labor and time and minimizes leakers.

Solder.—The solder used for sealing should be of standard composition. Where the sealing is done by hand the solder is most conveniently used in the form of thin bars or wire. The wire is usually bought already cut up in segments, each segment furnishing solder enough to seal one can. In the newer types of soldering machines the solder wire is automatically fed from spools. The smaller the opening of the can, the less solder is necessary to complete the seal. An opening smaller than three-eighths of an inch in diameter, however, cannot conveniently be used, owing to the difficulty of filling the can with this viscous product. The essential points of satisfactory sealing are: no "leakers," neat work, rapid work, small amount of solder. An experienced sealer will use from two to three pounds of solder per thousand tin cans with moderate-sized openings. He will seal from fifteen hundred to twenty-five hundred cans per day.

Soldering Flux.—The use of solder requires the application of soldering flux, to prepare the surface of the tin for the solder. The flux always precedes the solder. When the hot solder is applied, some of the flux is bound to sweat through, between cap and can, gaining access to the interior of the can. The common practice of using zinc chloride or other similar acid fluxes, which are highly poisonous, therefore, cannot be too strongly condemned. There are other fluxes which are absolutely harmless, and which, if properly used, give satisfactory results. Dry, powdered rosin or rosin dissolved in alcohol or gasoline, are of this class. Ammonium chloride, while used in most tin shops, is not as well suited for this purpose. Solder is now available containing the necessary flux in its interior. Thus solder wire as fed from spools for machine soldering may be hollow, the tube being filled with powdered rosin.

Gas Supply.—A plentiful and steady supply of gas is essential. Where natural gas or gas from a municipal corporation is not available, the factory must rely on its own generator. For the needs of the condensery a gasoline gas plant consisting of gas generator with carburetor, positive pressure blower and escape valve, heavy galvanized iron storage drum, mercury gauge and necessary valves and fittings may serve the purpose.

SANITATION IN PACKING

Investigation of the various causes of deterioration of sweetened condensed milk has repeatedly shown that many serious and costly condensed milk defects are caused by contamination of the condensed milk after it leaves the pan. The development of white and yellow buttons due to mold growth, and the rapid thickening with age when due to bacteria, are examples of defects that can only occur as the result of recontamination of the condensed milk. Most of the other bacterial defects are also often the result of contamination between pan and sealed tin.

The best known sources of such recontamination are unclean cooling equipment, unclean filling machines, unclean tin cans and caps. Too much attention cannot be given this matter of keeping all equipment, from pan to storage tanks, in clean and sanitary condition and to use sterilized cans only. The cans are made from tin plate of varying degrees of cleanliness and handled in a manner that makes impossible the prevention of contamination. Often the cans are stored in places where they are exposed to dust and contaminated air. To fill such cans with condensed milk is bound to contaminate the milk, and in many cases this contamination may shorten its life and lead to disastrous and costly defects.

All tin cans should, therefore, be sterilized before filling. A practical sterilizer for empty tins may be readily devised in the form of a heated tunnel in which the tins pass in inverted position over a series of gas burners. This method is used successfully in many European condenseries and it has solved for them, in a large measure, the problem of preventing the appearance of buttons and of eliminating bacterial thickening. The caps also should be sterilized and kept sterile until needed. The cans should be sealed hermetically in order to prevent subsequent contamination and to keep out air that accelerates microbic growth.

It is important also that the condensed milk be tinned as soon as possible after cooling. Before it is tinned the milk is exposed to air. This encourages the growth and multiplication of those microorganisms that thrive only in the presence of air, as for instance the yeast germs. Certain species of yeast secrete enzymes that are capable of fermenting sucrose causing bloats. These enzymes do not require air for their action. Hence, if the condensed milk has been exposed to air before tinning, long enough to cause profuse growth of these yeasts, their enzymes may be sufficient in quantity to ferment the product after tinning. Prompt tinning of the cooled condensed milk, therefore, may well be looked upon as an important precaution against the appearance of bloats.

For further substantiation of the importance of maintaining in the factory a standard of cleanliness and sanitation that reduces contamination to the minimum, the conclusions of Savage and Hunwicke[161] of the Department of Scientific and Industrial Research of London, England, are here cited. These investigators made a most comprehensive study of bacterial defects of sweetened condensed milk. The summary of their splendid report is as follows:

"The bacteriological sections of this report show very clearly that the main cause of tins becoming unsound is the presence and growth of fermenting yeasts. If these can be prevented from gaining access, or supposing a few have entered, the conditions maintained so that they cannot multiply, then most of the condensed milk manufactured will remain sound and wholesome.

"1. Heating of milk before condensation must be efficient. Our results show that yeasts are abundant in most of all milk samples.

"2. Cooling of condensed milk must be done so as to avoid air contamination as much as possible. This is undoubtedly the chief defect noticeable in the many factories visited.

"3. Very special attention is necessary as regards the pipes which convey the condensed milk; (they should be taken apart daily and cleaned with hot soda water; steam is not efficient as a means of cleaning).

"4. It is of great importance that the condensed milk should be canned as soon as possible.

"5. Good, air-tight tins only should be used. Our results show that an air-tight tin is a very important factor. A few yeasts, even if they are gas producers, do not matter so much as long as they cannot grow. If the tins are not air-tight, then one of the main conditions favorable to the multiplication of the yeasts is supplied.

"If these five precautions against decomposition were always followed up, we believe the percentage of unsound tins would be reduced to negligible proportions."

For further details on defects in sweetened condensed milk see Chapter XXV.

Vacuum Packing of Sweetened Condensed Milk.—The cooled sweetened condensed milk contains considerable quantities of air and gases. As previously explained, exposure to air is favorable to the development of yeast cells with which the condensed milk may be contaminated. It is therefore desirable to eliminate the air contained in the cooled condensed milk as completely as possible. This is especially important in the case of condensed milk intended to be tinned.

The growing appreciation, on the part of the manufacturer, of the detrimental effect of air in condensed milk has led to the now common practice of vacuumizing the condensed milk before filling into the tins. To this end a vacuum is drawn on the sweetened condensed milk storage tanks, so that the cooled milk that enters them is vacuumized. These tanks are equipped with a slowly revolving impellor which is kept in constant motion while the tanks are being filled and after filling until the condensed milk is removed to the filling machine.

Vacuum sealing of the tins, however, has not proved satisfactory and has been largely abandoned. While desirable from the standpoint of absence of air in the case of hermetically tight tins, experience has shown that the tins with solderless seals are seldom absolutely air-tight. When such tins are vacuum packed, outside air will enter due to the pressure difference between the atmosphere and the inside of the vacuumized tin.

With the uncertainty of sanitary conditions incident to storage and transportation, there is thus danger of damaging contamination. The air thus drawn into the tin will remain there, even when the vacuum has been destroyed, or when, due to wide fluctuation in atmospheric temperature, the pressure difference has been reversed, causing the pressure in the tins to be greater than that of the surrounding atmosphere. The viscous milk seals the microscopic leaks from the inside and locks in the air.

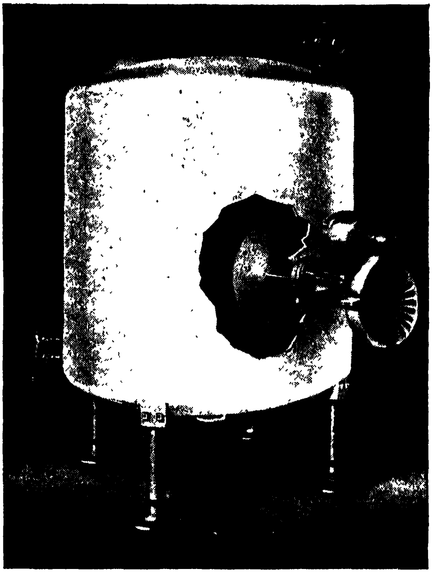

Fig. 63A. Glass-lined tank with impellor for vacuumizing
Courtesy of The Pfaudler Company

It appears, therefore, that vacuum packing in tins with solderless seals does not eliminate and may even augment the danger of contamination with impure air. This has in fact been the experience in commercial packing and distribution of sweetened condensed milk. On the other hand, vacuumizing the product between cooler and filling machine by discharging the cooled milk into a vacuumized storage tank and holding it under vacuum, preferably with slow agitation, until ready to pack into the tins, has been found an effective means to minimize the danger of damaging contamination of the milk prior to filling.

PART III

Manufacture of Unsweetened Condensed Milk

CHAPTER XII.

Definition.—Unsweetened condensed milk is manufactured and placed on the market under three different trade names, namely, evaporated milk, plain condensed milk and concentrated milk.

EVAPORATED MILK

Evaporated milk is cow's milk condensed in vacuo at the ratio of about two to two and one-half parts of fresh milk to one part of condensed milk. It is of the consistency of thin cream and reaches the market in hermetically sealed cans varying in size from eight ounces to one gallon. Evaporated milk is preserved by sterilization in steam under pressure.

General Description of Equipment Needed for Manufacture of Evaporated Milk.—The equipment needed and the flow of the milk from weigh can to sterilizer are shown in Fig. 64. It is briefly as follows:

From the weigh tanks (1) where the farmers' milk is inspected, weighed and sampled, the milk is pumped (3) through filter (4) over cooler (5) into holding tanks (6) where it is standardized to the desired ratio of fat to solids not fat. From the holding tanks it is pumped through forewarmer (8) into hot well (9). From the forewarmer the hot milk reaches the vacuum pan (10) and the condensed milk is discharged from the bottom of the pan through sampling valve (22) into drop tank (16).

For the continuous process of condensing, requiring means for a continuous pan discharge while condensing, a low pressure pump (14) assisted by check valve (13) and primer (12) is provided. The condensed milk may pass to the homogenizer (17) without the use of the drop tank (16) but the availability

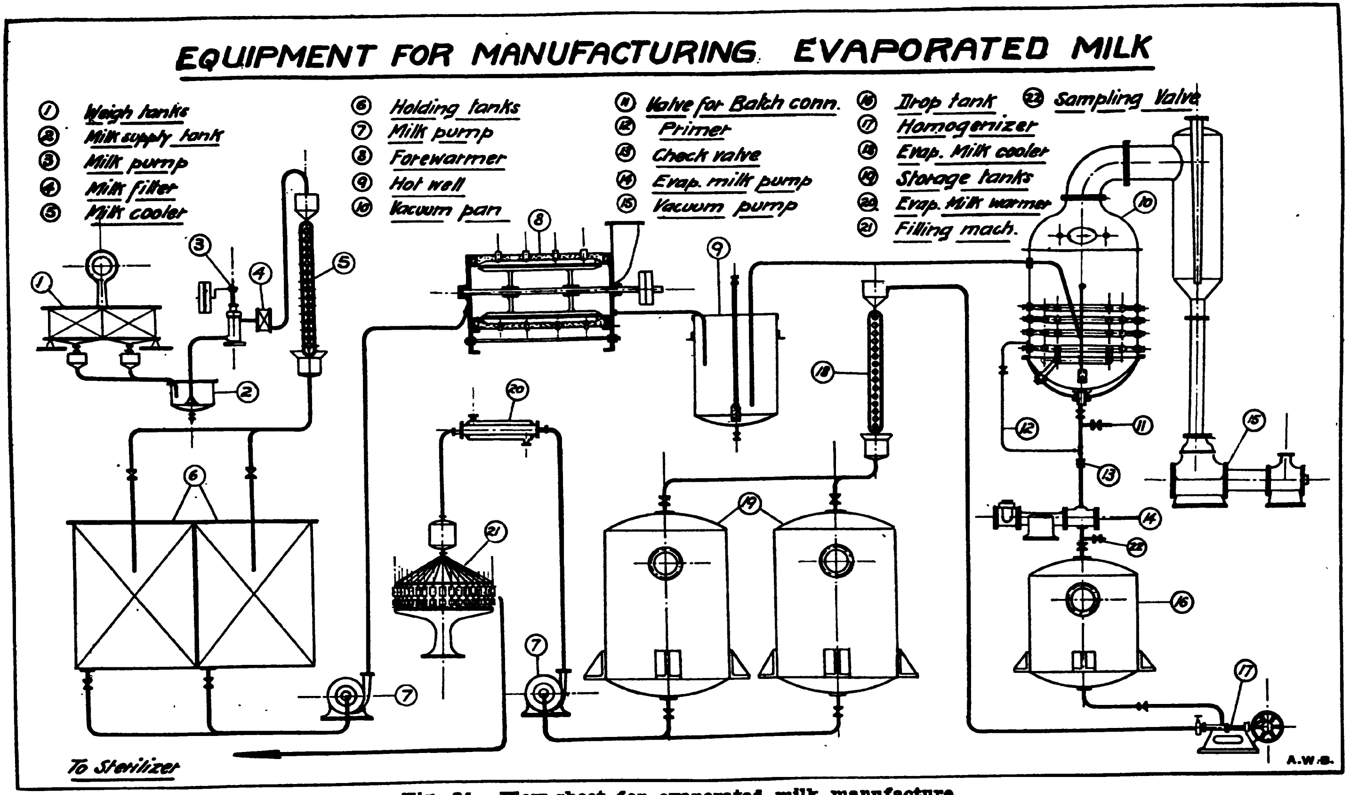

Fig. 64. Flow-sheet for evaporated milk manufacture

of the drop tank may prove helpful in case of accidental interruptions in the flow of the milk between pan and storage tanks (19) and especially when using the batch system of condensing.

From the drop tank the condensed milk passes through homogenizer (17) over cooler (18) into storage tanks (19), where it is standardized for total solids and held cold until ready to be tinned. The standardized milk, made homogeneous by thorough agitation in the storage tanks, is then forced from these tanks by pump (7) through evaporated milk warmer (20) into a supply tank that feeds the filling machine (21) by gravity. From the filling machine the filled and sealed tins are conveyed through a leak detecter to the sterilizer where they are subjected to steam under pressure, destroying the ferments contained in the milk and giving the evaporated milk the necessary keeping quality and the desired consistency.

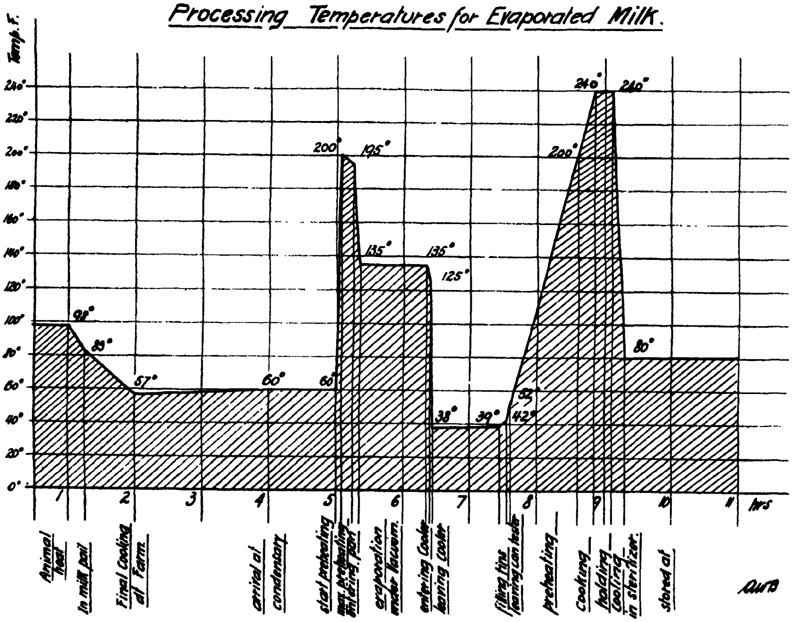

Fig. 65. Temperature flow-sheet for evaporated milk

Fig. 65 illustrates graphically the temperatures to which the milk is subjected in its journey from cow to finished manufactured product.

Inspection and Treatment of Milk Before Manufacture.—In the manufacture of evaporated milk the quality and normality of the fresh milk are of even greater importance than in the manufacture of sweetened condensed milk. This is due to the influence these factors have on the behavior of the evaporated milk in the sterilizer, as fully explained in Chapter III under "Milk Supply," and in Chapter XV on "Factors That Influence the Heat Coagulation of Evaporated Milk."

Efficient inspection of the milk on the receiving platform, therefore, is an integral and necessary step in the successful manufacture of evaporated milk. Aside from inspection by taste and smell, the use of rapid chemical tests adapted to the routine of the receiving platform, such as the acid test, or the alcohol test, or the phosphate test, may prove of material help. Such tests are especially valuable for confirmation in the case of doubtful cans and also at times when the condensery experiences sterilizer difficulties and it becomes necessary to ascertain the source of the troublesome milk.

The milk that has passed inspection is then weighed and sampled, filtered, cooled and collected in the holding tanks where it is standardized to the desired ratio of fat to solids not fat for which detailed directions are given under "Standardizing" of sweetened condensed milk in Chapter IV.

Addition of Casein-Stabilizers.—In factories where casein-stabilizers, such as sodium bicarbonate, di-sodium phosphate or sodium citrate are used for the control of coagulation in the sterilizer, it is usually preferable to add at least a portion of the required quantity of these reagents to the fluid milk before manufacture, as explained in Chapters XV and XVI.

FOREWARMING

Importance.—In the manufacture of evaporated milk, the forewarming is one of the most important of the several known factors upon which the heat stability of the evaporated milk during sterilization depends. High temperatures of forewarming and prolonged exposure to these temperatures diminish the viscosity and increase the stability of the milk toward sterilizing heat. This fact has been established by long experience in commercial manufacture and by extensive experimental investigation.

Temperature of Forewarming.—For average commercial conditions of manufacture forewarming to near the boiling point, preferably 95° C. (203° F.), and holding for 10 to 15 minutes, is considered most satisfactory from the standpoint of maximum stability consistent with a satisfactory body. Lower temperatures and shorter periods of holding increase viscosity and decrease heat stability. Temperatures above the boiling point produce maximum stability, but their use is accompanied by too great a decrease of viscosity to give the evaporated milk the desired body, and they tend toward the appearance of an abnormally dark color.

In order to take the fullest advantage of the viscosity- and heat coagulation-controlling effect of forewarming it is necessary to adjust the temperature and time of forewarming to the character of the milk received, as influenced by seasonal, territorial and climatic conditions, and to the subsequent treatment given the milk in the process of manufacture, such as concentration of milk solids-not-fat, pressure used in homogenization, the addition of chemical stabilizers, the sterilizing process, etc. The factors that determine viscosity and heat coagulation and the diverse conditions influencing them are discussed in detail in Chapter XV.

Equipment for Forewarming.—In the forewarming of milk for evaporated milk the same equipment—the hot well—as described under "Sweetened Condensed Milk," Chapter IV, is generally used, and the heating is accomplished by blowing "live" steam into the milk, or by means of the steam jacketed kettle with agitator, or both. The dilution of milk with steam condensation resulting from heating by blowing steam direct into the milk may be materially minimized by the use of the steam jacket until the temperature of the milk reaches about 160°F. and then finishing the heating with "live" steam.

Forewarming by the Use of the Recirculating Hot Well, Tubular Heater and Retarding Hot Well.—It has been shown in previous paragraphs that the stabilizing effect on evaporated milk due to forewarming of the fresh milk increases with increased temperature and time of heating. The application of these facts has developed forewarming methods so effective in improving the heat stability of evaporated milk as to avoid sterilizing difficulties without the addition of chemical stabilizers in the form of citrates, phosphates or carbonates.

One of these methods consists of forewarming by recirculating the milk through a tubular heater. This method is being successfully used in condenseries with large volume, where the condensing is done by the continuous process, but it is likewise applicable to plants with small volume and where the milk is condensed in batch units.

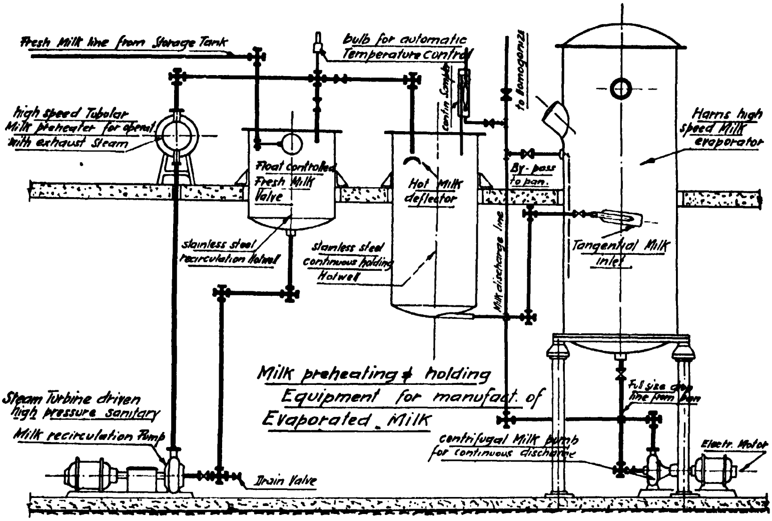
Fresh Milk line from Storage Tank
bulb for automatic Temperature control
contin. Sample
to Homogenize
high speed Tubular Milk preheater for operat. with exhaust Steam
Float controlled Fresh Milk Valve
Hot Milk deflector
By-pass to pan.
Harris high speed Milk evaporator
stainless steel recirculation Hotwell
stainless steel continuous holding Hotwell
Milk discharge line
Tangential Milk inlet
Milk preheating & holding Equipment for manufact. of Evaporated Milk
Full size drop line from pan
Steam Turbine driven high pressure sanitary Milk recirculation Pump
centrifugal Milk pump for continuous discharge
Electr. Motor
Drain Valve

Fig. 66. Unit for forewarning by recirculation and holding, with continuous discharge and automatic density tester

Courtesy of Arthur Harris & Co.

The equipment needed for forewarming by this system of recirculation is shown in Fig. 66. It consists of a recirculation hot well, designated here as "shallow hot well," with float-regulated milk intake and intake for recirculated milk; a high pressure centrifugal pump; a tubular heater; and a deep, retarding hot well, designated hereafter as "deep hot well."

The fresh milk flows by gravity through the float-operated valve into the shallow hot well. When it reaches the definitely established, desired level, the high pressure pump is started, circulating the milk from the shallow hot well, through the tubular heater and back into the shallow hot well.

When the milk in the shallow hot well has reached the desired forewarming temperature (190° to 205° F.), the valve in the heater discharge line leading to the deep hot well is opened and approximately 40 gallons per minute is drawn into the deep hot well. This transfer lowers the milk level in the shallow hot well, causing the float-operated valve to admit automatically 40 gallons of fresh milk.

The deep hot well is a continuous holding tank. Its depth is designed to hold the hot milk 12 to 16 minutes, according to the seasonal changes in the raw milk and the heat stability and body desired of the finished product.

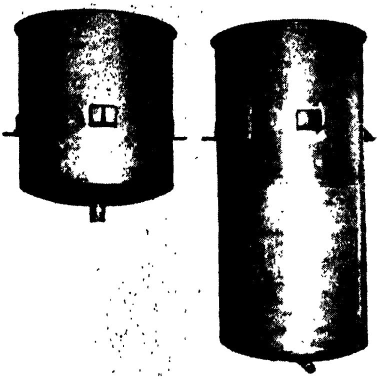

Fig. 67. Deep and shallow hotwells

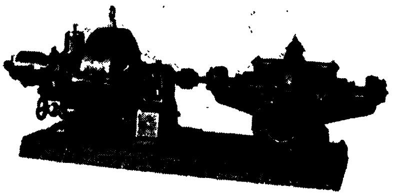

Fig. 68. Milk circulating pump

Courtesy of Arthur Harris & Co.

From the deep hot well the milk is forced into the vacuum pan by the atmospheric pressure. The heating in the tubular heater is done with exhaust steam or low pressure boiler steam. The temperature of the recirculating milk is controlled by means of a compressed air-regulated steam inlet valve to the tubular heater, which is operated by a pilot bulb in the milk discharge line of the heater.

The economy of operation of forewarming by recirculation may be materially improved by the use of a turbine pump in the place of the piston or electric drive high-pressure centrifugal pump. A relatively high velocity of the milk through the heater tubes must be maintained in order to minimize the tendency of the milk burning on the tube walls. This velocity requires a large amount of energy. The tubular milk heaters are designed for operation under low-pressure steam. When using a turbine steam pump for circulating the milk, the exhaust from the steam turbine furnishes the low-pressure steam for the heater, the turbine in this case serving as a pressure-reducing valve which utilizes the entropy of the pressure difference. Thus the steam supplying the turbine pump drives the pump and heats the milk. In this way, the cost of the power required to pump the milk through the heater is eliminated. This economy is further enhanced by the fact that the exhaust steam from the turbine pump is free of oil.

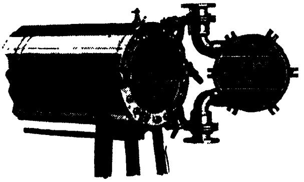

Fig. 69. The Peebles milk heater

Courtesy of Anderson-Barngrover Mfg. Co.

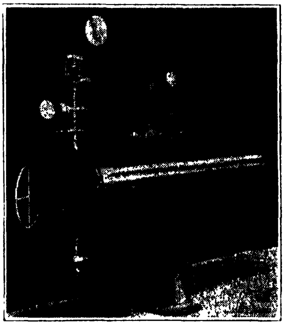

Fig. 70. The Scott milk heater

Courtesy of George Scott & Son, London

Seasonal Adjustment of Forewarming Temperatures.—Generally speaking, in the temperate zone and where the routine of breeding the cows aims to distribute milk production over the twelve months of the year, the tendency is for the natural heat stability of the milk to be greatest during the flush production of the summer months and lowest during late fall and winter. In regions where these seasonal differences prevail, therefore, heat coagulation difficulties in fall and winter may be materially improved by using the higher forewarming temperatures, or longer periods of heating, or both. During the summer months, when the natural tendency is toward low viscosity, lower temperatures or shorter periods of heating, or both, will assist in improving the body of the evaporated milk.

Forewarming Evaporated Milk for Export Market.—The export market demands a higher concentration of milk solids in evaporated milk than the home market in the United States. As the concentration of milk solids-not-fat and of fat increases, the heat stability diminishes. High forewarming temperatures are particularly effective in improving the heat stability of milk condensed to a high concentration of solids-not-fat. The use of high forewarming temperatures on milk intended for the export market of evaporated milk, therefore, assists in avoiding troublsome heat-coagulation difficulties with such milk in the sterilizer.

CONDENSING

The forewarmed milk is condensed in the vacuum pan, in a similar manner as in the case of sweetened condensed milk, the chief difference being in the ratio of concentration. Evaporated milk, especially the product manufactured in the United States for domestic consumption, is not condensed to as high a concentration as sweetened condensed milk. Most of the evaporated whole milk made for the home market is condensed sufficiently only to meet the present U. S. Federal requirements of not less than 7.8% milk fat and 25.5% total milk solids. The U. S. standard further provides that the sum of the percentages of milk fat and total milk solids be not less than 33.7. This requires a concentration of about 2¼:1; averaging approximately 2.23 pounds of fluid whole milk to make one pound of evaporated milk. Many of the European brands of evaporated milk show a considerably higher total solids content, suggesting a concentration of 2½ to 2¾:1.

In factories with large volume of make in the United States, and to some extent in other countries, the batch system of condensing for the manufacture of evaporated milk has been superseded by the continuous system. In this system the milk in the pan is kept at a constant level, the pan discharges evaporated milk of the desired density continuously and the fluid milk supply is regulated to synchronize with the rate of evaporation. This system is explained in detail in Chapter XIX under "Condensing by Continuous Process."

STRIKING THE BATCH

The striking, or sampling and testing for density, of evaporated milk is more easily accomplished than that of the viscous, syrupy, sweetened condensed milk. When the evaporated milk has reached the desired concentration its consistency resembles that of rich milk or thin cream.

Samples are drawn from the vacuum pan as described under sweetened condensed milk and the density can be readily determined by means of a hydrometer. Baumé hydrometers, registering from 5 to 15° B., are generally used. As it is important that the determinations be accurate, the hydrometer should be sensitive and its scale should be subdivided into tenth degrees. The batch should be "struck" at a uniform temperature, say 120° F., so as to avoid misleading readings.

Hunziker[56] found the influence of temperature on the Baumé reading to be .0313° Baumé for each degree Fahrenheit. Mojonnier and Troy[42] determined Baumé degree variations for different ranges of temperature and found this variation to be different for high and low temperatures. Their results show that between 40 and 80° F. each degree Fahrenheit is equal to .025° B., between 80 and 110° F., .034° B. and between 110 and 140° F., 039° B.

The specific gravity of evaporated milk varies with the ratio of concentration and the relative proportion of fat and solids not fat. The range of specific gravity for evaporated milk of varying concentrations extends from about 1.05 to 1.075 at 15.5° C. (60° F.). According to Mojonnier and Troy, the specific gravity of evaporated milk that conforms with the Federal Standard of 7.8% fat and 17.7% solids not fat is 1.0662 at 60° F. and 1.0518 at 120° F., with a corresponding Baumé reading of 9.0 and 7.14, respectively. They ascertained that, for evaporated milk of the above composition, a difference of .10° Baumé is equal to about .30% of total solids.

It is important to secure correct and exact Baumé readings for two principal reasons. Factory efficiency demands the manufacture of a product of definite density and composition. In the second place, the concentration of the evaporated milk affects the behavior of the milk in the sterilizer.

As concentration increases the heat coagulation point drops.

Holm, Deysher, and Evans[57] studied the effect of different degrees of concentration. The results indicate that this effect is very marked, which is in accordance with condensery experience. Holm and co-workers found that the relationship of the change of coagulation temperature to concentration was not constant. At high concentrations there was a greater variation in coagulation temperature for changes in concentration than there was at the lower concentrations. Their figures show that, when the per cent solids not fat is between 16 and 26 per cent, every per cent difference in concentration caused a change in temperature of coagulation of about 1.25 to 1.50° C. (2.25 to 2.7° F.). In the case of skimmed evaporated milk the change was somewhat greater and the drop in coagulation temperature was greater with milk of inferior quality.

The above citation may suffice to emphasize the importance of accurate "striking." To facilitate this work it has been found advisable for the operator to use a pail of water of the proper temperature when he "strikes" the batch. The hydrometer cylinder filled with the evaporated milk is immersed in the water and the reading is taken. This assists in insuring the Baumé reading at a definite, known temperature. Where the "striking" cup or sampler is attached to the body of the pan, the striking may also be done by inserting the hydrometer direct in the stationary sampler, but the usual method is to use a special hydrometer cylinder which is filled either from the sampler at the bottom of the pan or from the striking cup projecting from the wall of the pan body. For continuous condensing the evaporated milk is caused to flow through a hydrometer cylinder continuously and the hydrometer functions automatically, see Chapter XIX.

SUPERHEATING THE BATCH

Superheating is not now a part of the standard process of making evaporated milk. Superheated products are generally confined to "Plain Condensed Bulk Milk," which is neither canned nor sterilized, and is sold in bulk. Directions for its manufacture, including superheating, are given in Chapter XVIII.

There are some manufacturers of evaporated milk, however, who insist on the advantages of superheating evaporated milk, claiming that it minimizes the danger of the formation of too firm a curd in subsequent sterilization, while at the same time it improves the body and assists in the prevention of fat separation. Superheating of evaporated milk is not essential in the production of quality and marketable properties. It is not improbable that its advantages are much overestimated. In most factories the superheating process is not applied to evaporated milk.

FINISHING AND STANDARDIZING THE BATCH

As soon as the desired point of concentration has been reached, as indicated by the Baumé reading, the steam valves are closed, the process of condensing is stopped as described in Chapter VIII, see "Finishing the Batch," and the milk is drawn from the pan and cooled.

The standardization of the ratio of fat to solids not fat is usually most conveniently done in the milk before condensing, as explained in previous paragraphs of this chapter. The standardization of the batch after condensing, therefore, need extend only to adjusting the concentration to the desired per cent of total solids.

Knowing the Baumé degrees that correspond with an evaporated milk of the desired per cent total solids for milk with a given ratio of fat to solids-not-fat, standardization of the finished batch may be eliminated entirely by carefully carrying the condensing process just far enough to secure the correct Baumé reading at the proper temperature. A skillful and experienced operator is capable of thus producing evaporated milk very close to the desired composition by this method and without resorting to methods of readjusting the composition of the finished batch.

Where maximum accuracy of composition is desired, however, some method of determining the exact composition of the batch and adjusting it to the exact percentage of total solids is generally used. In this case the usual practice is to overcondense the batch slightly (about 1 to 2° B. beyond the desired striking point) and then reduce the concentration to the correct point by the addition of water. The correct amount of water to add in this case is calculated as follows:

1. Determine the weight of the original fluid milk and the weight of the finished batch.

2. Determine the ratio of concentration necessary by dividing the per cent of total solids desired in the finished product by the per cent total solids in the original fluid milk.

3. Determine the desired weight of the finished product by dividing the weight of original fluid milk by the ratio of concentration.

4. Deduct the actual weight of the batch from the desired weight of the finished product. This gives the pounds of water to add.

Example:

Original fluid milk in batch weighs 11,200 pounds, containing 12.5% total solids. Total solids desired in finished batch is 28%. Actual weight of the finished batch is 4,800 pounds.

Answer:

Ratio of concentration desired is $\frac{28}{12.5} = 2.24$ to 1.

Weight of finished batch needed is $\frac{11,200}{2.24} = 5,000$ lbs.

Amount of water to add, 5,000 — 4,800 = 200 lbs.

Proof:

Total solids in original fluid milk is $\frac{11,200 \times 12.5}{100}$ = 1,400 lbs.

Per cent total solids in standardized batch is $\frac{1,400 \times 100}{(4,800 + 200)}$ = 28%

Determining Weight of Finished Batch.—This may be done in any one of the following three ways:

1. Using a drop tank with scale arrangement in which the entire batch is weighed.

2. Measuring the batch in the drop tank or storage tank by means of a graduation on the inside of the tank or by the use of a graduated measuring stick. The accuracy of the result here varies with numerous factors such as accuracy of graduation on tank or on measuring stick, surface area of milk and amount of foam in milk. Gauges of various types, such as the Green Gauge and other gauges operating on the hydrostatic

principle have also been used for this purpose with varying success.

3. Calculating the ratio of concentration on the basis of the total solids present in the original fluid milk and in the finished batch. This requires the accurate testing of both the fluid milk and the finished batch for total solids, and its accuracy depends particularly on the representativeness of the samples obtained. The calculations are illustrated by the following example:

Example:

Original fluid milk weighs 9,200 lbs., containing 12.5% total solids. Total solids contained in finished batch is 28.75%. Total solids desired is 28%.

Answer:

Desired ratio of concentration is $\frac{28}{12.5} = 2.24$ to 1.

Actual ratio of concentration is $\frac{28.75}{12.5} = 2.3$ to 1.

Desired weight of finished batch is $\frac{9{,}200}{2.24} = 4{,}107$ lbs.

Actual weight of finished batch is $\frac{9{,}200}{2.3} = 4{,}000$ lbs.

Amount of water to add = 107 lbs.

Proof:

Total solids in original fluid milk is $\frac{9{,}200 \times 12.5}{100} = 1{,}150$ lbs.

Per cent total solids in standardized batch is $\frac{1{,}150 \times 100}{(4{,}000 + 107)} = 28\%$.

IRRADIATION OF EVAPORATED MILK

The practice of irradiating evaporated milk has been adopted by a number of the larger milk condenseries in this country and appears to be destined to become an integral part of the process of manufacture.

Purpose.—As explained in Chapter XXIV under "Vitamins," due to our present mode of living, the limited amount of sunshine available to the average child and adult is insufficient to provide an adequate supply of vitamin D, and this vitamin is not available in the necessary protective amounts in the normal diet. But by irradiating milk, which already contains the pro-vitamin ergosterol, by exposure to ultra-violet light, activation of the milk ergosterol takes place and the milk may thus be fortified with an amount of vitamin D that fully provides the requirements of the body to protect it against the disease of rickets.

These discoveries have led to the development and use of milk irradiating equipment by the dairy industry for the purpose of imparting to fluid, dried or evaporated milk, a uniform protective vitamin D potency. Milk so treated is properly termed "Irradiated Vitamin D Milk."

Method of Irradiation.—The process briefly consists of exposing the milk, or evaporated milk, in a thin layer to ultraviolet rays under controlled conditions insuring, through photochemical action on the ergosterol or pro-vitamin already present, the production of a protective Vitamin D potency in the milk.

As shown by Putnam,[274] in the "Manufacture of Irradiated Vitamin D Evaporated Milk," the arrangement of equipment which consists of a drop tank, an automatically controlled and metered variable-speed milk pump, the Irradiator proper complete with the required accessories, and Irradiator discharge

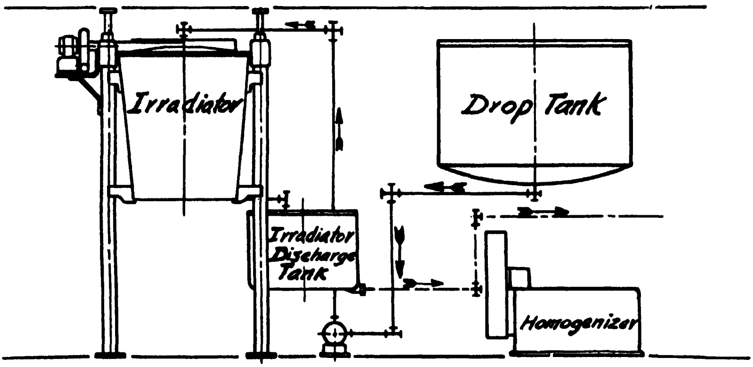

Fig. 71. Irradiator flow-sheet for evaporated milk
Courtesy of Creamery Package Mfg. Co.

tank, as shown in diagram Fig. 71, is used. Instead of irradiating the fluid milk, the evaporated milk is irradiated after condensing in order to economize equipment, electric current and time of operation. It passes from the vacuum pan through a set of coarse and fine strainers into a drop tank which serves as a reservoir where it is held at a temperature of 130 to 145° F. From here it is pumped into the Irradiator distributor trough at a predetermined rate. The evaporated milk then flows in a thin film (about 0.25 mm. in thickness) over the inner surface of the cylinder and the pro-vitamin is activated into Vitamin D during the 3 second exposure to the therapeutic carbon arc light suspended in the center of the Irradiator. This is illustrated in the cut-away section of the Irradiator shown in Fig. 72. The irradiated evaporated milk then flows by gravity into the Irradiator discharge tank that feeds the homogenizer.

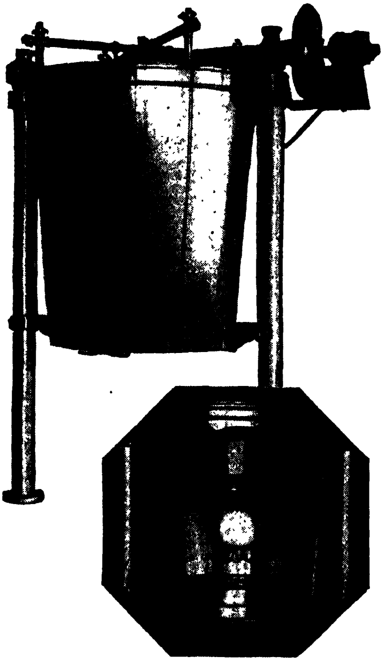

Fig. 72. Milk Irradiator
Courtesy of Creamery Package Mfg. Co.

The process of irradiation is positively controlled by means of a metering type pump, set and sealed at the capacity of the equipment and by means of a recording irradiator ammeter on which the electrical energy input is recorded as well as the on and off operation of the milk pump. The electrical energy input is automatically controlled to 60 amperes at 50 volts and insures a uniform ultra violet output from the lamp.

It has been found most efficient to irradiate the evaporated milk while hot and before homogenization, both from the standpoint of capacity and quality of the finished product, as the hot milk produces a thinner, better film and less foam in flowing over the Irradiator. The capacity of the Irradiator at the present time is 5,000 pounds per hour with the lamp operating at 60 amperes and 50 volts. Numerous bio-assays by the Wisconsin Alumni Research Foundation have shown that by operating under these conditions, it is possible to obtain a potency of 45 Steenbock units per 14½ ounce can of evaporated milk, or 50 units per quart when reconstituted 1 to 1 with water. This is the accepted standard for Irradiated Vitamin D fluid milk. The flavor and other properties of the evaporated milk appear not to be perceptibly altered by irradiation.

CHAPTER XIII.

HOMOGENIZING, COOLING AND PACKING

HOMOGENIZING

Purpose.—The purpose of homogenizing is to avoid objectionable fat separation in the evaporated milk after manufacture. Homogenization of evaporated milk had its beginning in this country approximately a quarter of a century ago and since 1910 it has been recognized and used by the industry as an integral part of the process of manufacture.

Prior to the introduction and use of the homogenizer the tendency of fat separation in evaporated milk was a constant menace to the successful manufacture of a marketable product. A heavy layer of thick cream formed in the top of the tins in storage, and often churned into lumps of butter in transit from the factory to store and consumer. This rendered the product unmarketable, brought serious complaints and caused heavy loss to the manufacturer. This tendency of fat separation was most pronounced in milk rich in fat and in which the large fat globules predominated, such as is the case with milk produced in Jersey and Guernsey localities.

In the pre-homogenizer days the formation of a soft curd in the sterilizer was practically a necessity in order to give the evaporated milk sufficient viscosity and body to prevent subsequent fat separation. This was accomplished with more or less success by superheating or "double cooking" the evaporated milk after condensing, or by prolonging the period of "bringing up" the heat in the sterilizer as was usually accomplished by intermittent stopping of the reel, or both.

The homogenizer has eliminated fat separation as a serious problem in the manufacture of evaporated milk. While homogenization at a pressure sufficiently high to accomplish dependable permanency of fat dispersion lowers the heat stability of the milk somewhat, it actually improves the control of heat coagulation, because it eliminates the need of precautions to prevent fat separation, which themselves invite heat coagulation uncertainties and difficulties.

Homogenization thus not only furnishes a dependable solution of fat separation difficulties, but it makes unnecessary the extension of the period of sterilization to the point of producing a suitable jell. It shortens the sterilizing process and largely eliminates the need of shaking. The shorter heat exposure has the further advantage of preventing objectionable darkening of color. It makes possible the preservation of the much desired natural, light, creamy color in the finished product.

Homogenizers.—The homogenizer is a special type of high pressure, multiple piston pump, forcing the milk, (or other liquid), through greatly restricted openings or valves. In order to provide a more uniform pressure and flow, the pistons are operated by eccentrics in succession. These multiple pumps are single acting, each cylinder having a suction and a discharge valve discharging into a common manifold which leads to the homogenizing head. The size of the opening of the homogenizing valve is adjusted by the turning of a hand-operated wheel which controls the tension of a heavy spring pressing against the valve. For evaporated milk the homogenizer is usually operated at a pressure range of 2,500 to 3,000 pounds per square inch. In exceptional cases pressures as high as 3,500 to 4,000 pounds may be used. Because of these high pressures it is important that the pistons fit accurately and are well packed. In order to insure dependable homogenizing efficiency that

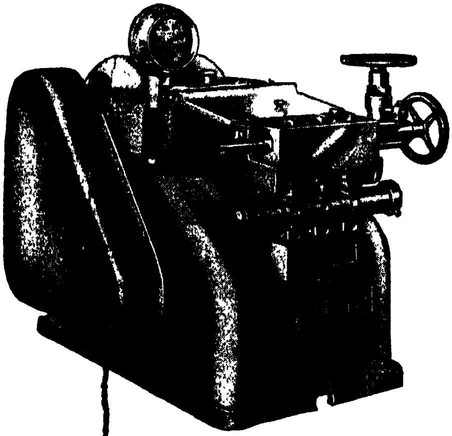

Fig. 73. Manton-Gaulin homogenizer
Courtesy of Gaulin Manufacturing Co.

makes possible the maintenance of a steady pressure and a uniform homogenization effect on all parts of the milk passing through, the homogenizing valve must be kept smoothly ground to insure freedom from scores, grooves and similar defects that would destroy efficiency and completeness of homogenizing effect. The cylinder valves, likewise, need constant attention and require regrinding at reasonable intervals so as to prevent leakage which interferes with uniformity of pressure. Proper tightening, and renewal when necessary, of the piston packing is important. Its inevitable hardening and other defects, such as mechanical dislodging, invite a leaky condition.

The Function of the Homogenizer.—Forcing a liquid through microscopically fine appertures at such high pressures greatly increases the velocity of travel. The high velocity with which the milk passes through the homogenizing valve and impinges on the wall of the valve chamber, and the sudden release of this pressure when escaping from the valve, are in all probability responsible for the effect on the milk produced by homogenization.

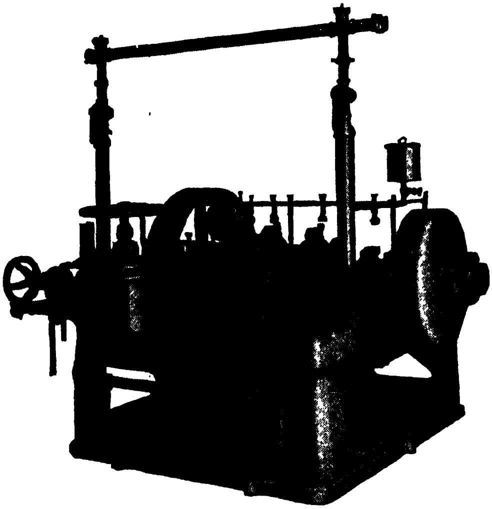

Fig. 74. The Progress homogenizer
Courtesy of Creamery Package Mfg. Co.

Recent experimental study on the efficiency of homogenizers by Doan and Minster[58] further shows that the force with which the liquid strikes the wall of the chamber surrounding the valve is affected, aside from the velocity, by the distance between valve and wall and by the angle of impact. Their results emphasize that, other things being equal, the shorter the distance between valve and chamber wall and the more nearly the liquid strikes the wall at a right angle, the greater is the homogenizing efficiency.

The most noticeable change brought about by homogenization is a marked decrease in the size and increase in the number of the fat globules. Recent experimental observations suggest that this finer dispersion of the fat globules in turn is responsible for diverse other effects produced by homogenization. The practical effect as related to fat separation and its prevention may be considered threefold:

1. The fat globules are divided into such small units that their buoyancy is no longer sufficient to readily overcome the resistance of the surrounding liquid. Their upward movement is greatly impeded, if not entirely prevented.
2. This failure to respond to the force of gravity is made more complete by the fact that in this finely dispersed phase the surface area of the fat globules has been greatly augmented, increasing the protein coverings which are known to form at the fat-liquid interfaces. This increases the specific gravity of the fat globules and further diminishes their buoyancy.
3. Homogenization increases the viscosity of the evaporated milk, thus further impeding the possible movement of the fat globules.

Effect of Homogenization on Size of Fat Globules in Evaporated Milk.—Conclusive data of experiments showing the comparative size of the fat globules in evaporated milk before and after homogenization are lacking. Unpublished results of microscopic examinations dealing with the effect of homogenization on the size of the fat globules in commercial manufacture of evaporated milk by Hunziker,[59] however, reveal a marked reduction in size in the homogenized product and the presence of uniformly small globules.

The most definite comparison of the effect of homogenization appears to be that furnished by Wiegner[60] who homogenized whole milk testing 3.13 per cent fat, using a pressure of 250 atmospheres (3,675 lbs.). He reports a reduction in size of fat globules from an average of 2.86 microns before homogenization to an average of 0.27 microns after homogenization. Rahn and Sharp[61] also studied the effect of homogenizing whole milk. They found that the fat globules are more finely dispersed in properly homogenized milk than in skimmilk.

In the case of evaporated milk which has inevitably been subjected to violent agitation at varying temperatures during forewarming, pumping, and boiling in the vacuum pan, the state of dispersion of the fat globules at the time of homogenization introduces an added uncertainty. Rahn and Sharp studied the effect of pumping and forewarming on milk containing 3.2% fat and found that such treatment caused a decrease of 14% in the number of fat globules with a diameter less than six microns and an increase of 16% in the number of fat globules with a diameter larger than nine microns.

Hunziker's[62] observations in treating heated cream at 145° F. under vacuum for the purpose of deodorizing, suggest that the type and violence of agitation involved in boiling under vacuum tends toward the formation of large aggregates of fat. The medium size fat globules became fewer. The microscopic field showed principally only large blotches of oil and some very small globules. Although neither the results of Rahn, who worked with milk, nor those of Hunziker, who treated cream, are strictly comparable to the situation in the case of evaporated milk, yet those results suggest the probability of a somewhat uneven fat dispersion and the presence of large aggregates of fat in evaporated milk at the time of homogenization, requiring a greater reduction in size of fat globules in order to accomplish the desired effect of satisfactory homogenization than has generally been believed to occur.

Effect of Homogenizing on Viscosity of Evaporated Milk.—Homogenizing increases the viscosity of evaporated milk. The cause of the increased viscosity of homogenized milk has not been fully explained but it is believed to be due to the increased adsorption of casein to the much larger surface area of the finely dispersed fat globules, thereby considerably augmenting the volume of the dispersed phase and diminishing the volume of the continuous phase. A change in the physical properties of the casein may also be involved in the effect of homogenization on viscosity.

Buglia[63] and Wiegner[60] show experimentally an increased viscosity of homogenized over unhomogenized whole milk. Wiegner reduced the average diameter of the fat globules in milk from 2.9 microns to .27 microns. He calculated from viscosity measurements that of the total milk casein, 2.27 per cent was adsorbed to the fat globules in the unhomogenized sample, while in the homogenized sample 25.2 per cent of the casein was adsorbed. He attributes the greatly increased adsorption of casein in homogenized milk to the enormously increased number of fat globules which offer a vastly increased adsorbing surface. He holds that this augmented quantity of casein adsorbed to the surfaces of the fat globules is responsisible for the increased viscosity.

Buglia found that while the viscosity, or outflow time, of homogenized whole milk is greater than that of the same milk before homogenizing, no increase in viscosity occurred in homogenized skimmilk. Skimmilk, being practically free from butter fat, obviously is incapable of materially increasing its adsorbing surface. Buglia further reports a slight increase in the electrical conductivity of homogenized milk, while Wiegner failed to find any difference in this factor. Both Wiegner and Buglia, however, observed a slight decrease in osmotic pressure due to homogenization. Rogers, Deysher and Evans[64] also demonstrated that homogenizing increases the initial viscosity of sweetened condensed milk, and experience in the manufacture of evaporated milk has amply shown that the higher the homogenizing pressure. the greater the increase in viscosity.

Recent investigations on homogenization of milk with a high fat content, and of cream, have further shown that the decrease in the size and increase in the number of fat globules due to homogenization are accompanied by an increase in the number and density of the fat clumps. It is believed that the increased viscosity is associated in some way with this fat clumping. It appears that the formation of clusters of butter fat globules as the result of homogenization does increase the viscosity in milk containing over 6 to 8 per cent fat, but it is not an important factor in the increase of viscosity of milk with a lower fat content. To what extent fat clustering plays a role in viscosity increases resulting from homogenization of evaporated milk has not been definitely established.

Effect of Homogenizing on Heat Coagulation Point of Evaporated Milk.—Homogenizing slightly lowers the stability of evaporated milk. This effect increases with increasing pressures as shown by the results of Deysher, Webb and Holm[65] whose graph is here reproduced. These investigators found that homogenization produced the lowest stability at a forewarming temperature of 60 to 65° C., while minimum stability of unhomogenized milk with 18% solids not fat and 8% fat occurred when forewarming at 70 to 75° C. When forewarming at 95° C., (203° F.), an increase in the homogenizing pressure up to 2,000 pounds had no effect on the heat stability; at higher pressures the heat coagulation point dropped slightly.

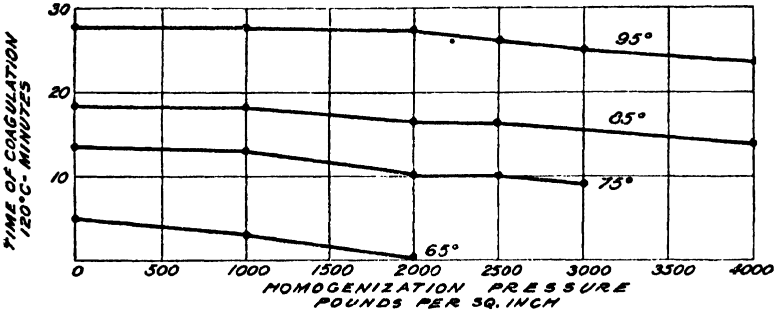

Fig. 75. Effect of homogenizing pressure for different forewarming temperatures on heat stability of evaporated milk
Reproduced from work of Deysher, Webb and Holm[65]

Effect of Homongenizing Temperature on Efficiency of Homogenization.—The temperature at which evaporated milk passes through the homogenizer affects the efficiency of homogenization. Generally speaking, and within certain limits, higher temperatures increase the efficiency. This is also shown by the work of Rahn[61] who homogenized whole milk at 20, 40 and 65° C., (68, 104 and 149° F., respectively). His results are given in Table 13.

As explained by Holm[66] an increase in temperature diminishes the magnitude of the forces of viscosity, surface tensions and interfacial tensions which must be overcome by the energy released by homogenization in order to accomplish the desired degree of dispersion. Temperatures below the melting point of

Table 13.—Relative Per Cent of Fat in Each Size Group of Fat Globules at Different Temperatures of Homogenization.

Size of fat globules	Temperature of homogenization 20° C. (68° F.)	 40° C. (104° F.)	 65° C. (149° F.)
Diameter, microns	Per Cent	Per Cent	Per Cent
0–1	2.3	1.9	4.3
1–2	29.3	36.7	74.4
2–3	23.3	21.1	9.0
3–4	29.8	25.2	12.3
4–5	0.0	15.2	0.0
5–6	15.4	0.0	0.0

butter fat, such as would apply to cooled evaporated milk, are obviously out of the question. Homogenizing at such low temperatures would tend to cause the fat globules to unite into butter granules, particularly in the case of liquids with a per cent of fat approaching that of cream.

In commercial operation the evaporated milk is usually passed through the homogenizer at or near the vacuum pan temperature, (130-145° F.). This temperature range favors maximum homogenizing efficiency, other conditions being equal.

Operation of the Homogenizer.—The homogenizer should be operated at the minimum pressure that will avoid fat separation in the evaporated milk. It has been shown in previous paragraphs that high pressure lowers heat stability and that aside from the influences of the natural character of the milk, the effect of homogenizing pressure on heat stability is affected by the temperature of forewarming, the concentration of the evaporated milk and the temperature at which the milk passes through the homogenizer.

Experiments by Deysher, Webb and Holm[65] indicate that when forewarming at temperatures near the boiling point, homogenizing pressures up to 2000 pounds have no effect on heat stability, but that higher pressures lower the heat coagulation point slightly.

It appears well to point out here that experience in commercial manufacture has amply demonstrated that excessively high pressure causes serious coagulation difficulties in the sterilizer. Under usual conditions a pressure of 2500 to 3000 pounds is ample to prevent fat separation. This pressure when applied to evaporated milk containing approximately 18 per cent solids not fat and 8 per cent fat, preheated to about 203° F. and homogenized at the usual pan operating temperature, (about 140° F.), does not lower the heat coagulation point sufficiently to augment the coagulation difficulties in subsequent sterilization of the evaporated milk.

If efficient homogenization is to be accomplished it is important that a uniform pressure be maintained and that all the milk be subjected to the full pressure. When starting the homogenizer the pressure is usually more or less irregular. It is therefore necessary, for best results, to by-pass the first few gallons of evaporated milk back to the intake until the pressure has become uniform and is under complete control; or to start the machine with water that is discharged on the floor, and turn on the evaporated milk flow only after the gauge uniformly registers the desired pressure.

The pistons, cylinders, valves and pipes of the homogenizer should be kept in sanitary condition. After homogenizing, the machine should be kept in operation, running water through it, until most of the remnants of evaporated milk are rinsed out; then hot water containing some strong alkali should be pumped through; this should be followed by clean, hot water and steam. Unless this machine is kept scrupulously clean, it may become a dangerous source of contamination, infecting the evaporated milk with spore forms that are exceedingly resistant and which are liable to pass into the finished product alive, in spite of the sterilizing process.

COOLING

The evaporated milk may be cooled by any method suitable for cooling market milk and market cream. The cooling is generally done by running the evaporated milk from the homogenizer over a surface cooler or through an internal tube cooler. Protection against contamination from equipment and exposure to air is important. In case the evaporated milk is not homogenized it should be cooled as soon as it leaves the vacuum pan.

Holding Tanks.—In factories with small make the cooled evaporated milk is usually held in tanks on the batch unit system. In many of the larger factories several or all the batches of one day's make are held in one or more large tanks. The latter system recommends itself especially where the continuous system of condensing or the continuous sterilizers are used. It makes for maximum uniformity of product and simplifies the problem of standardizing.

With the batch unit system, especially in plants with limited make, the evaporated milk is usually canned and sterilized on the same day. This makes unnecessary artificial refrigeration. The milk simply flows into a plain tank or vat, where it is standardized if desired, and from where it feeds the filling machine.

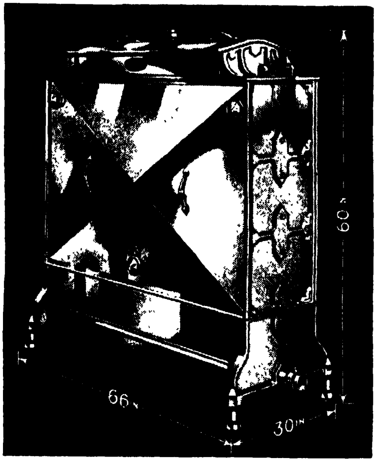

Fig. 76. The Film-flow cabinet cooler
Courtesy of Cherry-Burrell Corp.

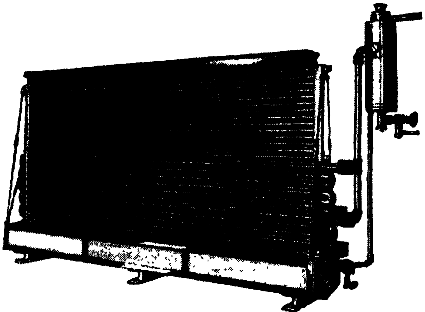

Fig. 77. The surface milk cooler
Courtesy of Creamery Package Mfg. Co.

In factories with large make and where batches of each day's operation are mixed, all or a part of the evaporated milk is generally held over and is canned and sterilized on the following day. This requires cooling to a lower temperature (about 40° F.) and holding the evaporated milk under refrigeration until ready to can. For this purpose either large jacketed tanks with agitators, preferably glass-lined, and heavily insulated on the outside, are used, or the tanks are single wall shells, installed in a refrigerated room. In some factories these tanks rest on scales so that the exact weight of the milk can be determined. If the system of operation requires that the evaporated milk be standardized at this point these tanks should be equipped with suitable agitators to insure thorough mixing of the batches. In the absence of storage tanks or vats with refrigerating facilities, as described above, the cooled evaporated milk may be filled into milk shipping cans, such as 10-gallon milk cans, and set in the cold room, or they may be submerged in a tank of ice water.

At this stage of the process the evaporated milk is not sterile, it contains no preservative such as cane sugar, and its concentration is insufficient to inhibit bacterial activity. At ordinary temperature, and especially during hot summer weather, its acidity will increase and other fermentations may occur, lowering its heat coagulation point and inviting sterilizing difficulties. Unless it is canned and sterilized promptly after it leaves the vacuum pan, or the homogenizer, prompt cooling to about 40° F. and holding it at that temperature until it reaches the sterilizer, are essential.

FILLING

The tins for evaporated milk range in capacity from eight ounces to one gallon. In the United States the standard 16 ounce tin has been reduced to a standard 14½ ounce tin by action of the American Evaporated Milk Association[67] in 1931. This reduction in the capacity of the tall size can had for its background the assumption that the American consumer thinks of evaporated milk in terms of quarts of fresh market milk. The 14½ ounces of average American evaporated milk is equivalent, in solid constituents and food value, to one quart of fluid milk of legal Federal standard. With reference to evaporated milk intended for international commerce there is as yet a great variety of package size and no promise of early standardization. The Permanent Committee of the International Dairy Federation[68] has under consideration the passage of a resolution to the effect "that the quantity of fluid milk represented by the contents of the tin be indicated on the label."

The openings in the tins range from the "Sanitary" can with top completely open, to the venthole can with an opening not exceeding one-eighth inch in diameter. The filling machines in use are of diverse designs, operating by gravity, under pressure, or under vacuum. The many advantages of the vent hole filler, its superior sanitary features, its accuracy of filling and its economic use of solder, (approximately 5 ounces solder will seal 1000 cans), have brought about its rapid and general adoption. It is estimated that over 90 per cent of the American evaporated milk is canned by the use of this type of filling machine.

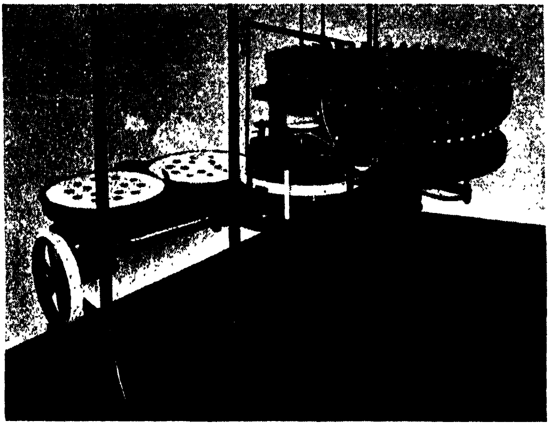

Fig. 78. The Dickerson evaporated milk filler
Courtesy of F. G. Dickerson Co.

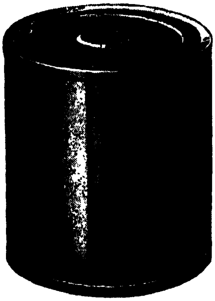

Fig. 79. The venthole can

In the filling of the venthole cans the foaming of the evaporated milk frequently causes serious trouble. The difficulty caused by foaming is twofold. It interferes mechanically with the proper filling of the tins, and its presence in the tins tends to cause the appearance of streaks of baked-on milk. Excessive foaming is now avoided in many factories by warming the cooled evaporated milk to a temperature of about 60° F. immediately before filling. For this purpose the evaporated milk may be conveniently pumped through a flash warmer in its passage from storage tank to supply tank of filling machine.

The filling machine is at best an enemy of sanitation, affording ever-recurring possibilities for damaging contamination. The fact that the evaporated milk is subsequently sterilized does not eliminate the disastrous consequences of unclean filling machines. In flowing through an unclean machine the milk is subject to contamination with millions of bacteria. The higher its germ content the more difficult it becomes to accomplish 100 per cent germ-killing efficiency in the sterilizer. Furthermore, decaying remnants of milk encourage invigoration of bacteria and spore-formation, thus augmenting resistance to heat and necessitating the employment of higher sterilizing temperatures or longer exposure. It is, therefore, important that the filling machine be kept clean and free from stale remnants of evaporated milk. The machine should be thoroughly washed and sterilized after each use.

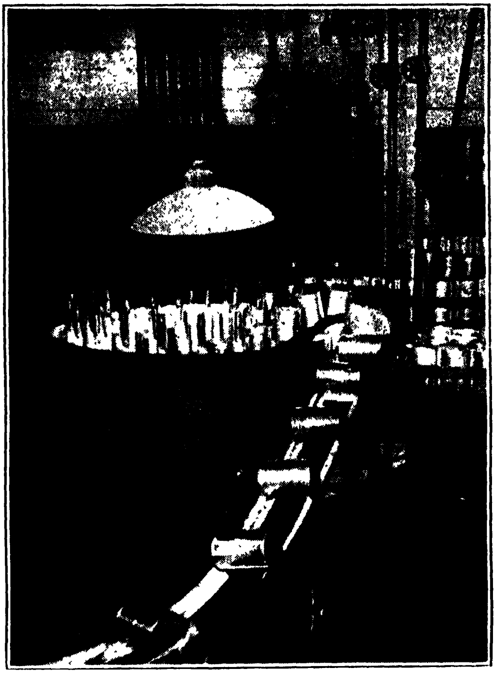

Fig. 80. The Henszey can tester
Courtesy of Otto Biefield Co.

CHAPTER XIV

STERILIZING

The sealed cans are now ready for the sterilizer. If they cannot be sterilized within an hour or two they should be submerged in ice water or placed in a refrigerating room until the sterilizer is ready for them. This precaution is especially advisable in summer.

Purpose of Sterilization.—The chief purpose of subjecting the evaporated milk to the sterilizing process is to kill all germ life and, thereby, preserve the product permanently. Aside from this, the manufacturer aims to gain another commercially important condition, namely, to give the product greater viscosity. This increased viscosity assists in keeping the fat in homogeneous emulsion, thereby diminishing its tendency to separate out after manufacture. Due to the greater viscosity the evaporated milk has a better body and more creamy consistency, lending the product a semblance of richness. In addition to complete destruction of ferments and development of the desired viscosity, successful sterilization involves the preservation of the light creamy color of the product. Excessive heat, especially too long exposure to sterilizing temperature, darkens the product, giving it a brownish color. The addition of excessive amounts of bicarbonate of soda further intensifies this tendency. The trade prefers evaporated milk that is of light color, resembling the natural color of cream.

Sterilizers.—There are fundamentally two general types of sterilizers in use. These are, the batch sterilizer and the continuous sterilizer. In the batch sterilizer, as the name implies, the batch is the unit. The successive steps of loading, heating, holding, cooling and unloading must be performed for one and the same batch before the sterilizer can be used for the next batch. In the continuous sterilizer the can is made the unit. Its natural contour, its cylindrical form, is taken advantage of. It rolls to, through and out of the sterilizer. The loading, heating, holding, cooling and unloading is continuous. Batch sterilizers are made in different sizes, and are serviceable in plants with small output as well as large. The continuous sterilizer is better adapted for large plants, such as plants receiving not less than about 50,000 to 100,000 pounds of milk daily. For details of the continuous sterilizer and its operation see Chapter XVII.

The Batch Sterilizer.—The batch sterilizer for evaporated milk was invented by John B. Meyenberg.[2] The machines now in use differ somewhat in details of design, but operate on the same general principle. The batch sterilizer consists of a large boiler-like, horizontal, steel cylinder or rectangular box, opening either at its side or at one or both ends. Its hollow interior carries a revolving framework, or spider cage, which accommodates the evaporated milk cans. It is provided with steam inlets and distributing pipes at the bottom, water inlets at the top, water outlet, blow-off vent, water-steam-and vacuum gauges, high temperature thermometer and preferably with automatic temperature control and recording accessories. The revolving framework or spider cage is usually equipped with direct motor drive.

The tendency of the industry in the United States in recent years has been to standardize on one or two types of batch sterilizers. These are known as the Fort Wayne sterilizer, and the Berlin sterilizer. In both of these types the interior framework or can carriage revolves on its own axis. In the one case there is a spider that accommodates the cans in trays (24—14½ oz. cans per tray); in the other case the carriage consists of one large perforated crate into which the cans are piled. The purpose of the revolving mechanism is to keep the cans in motion, turning them over and over during sterilizing operation. This hastens and makes more uniform, both the heating and the cooling. The agitation prevents the milk from cooking onto the inside of the cans. Too great a speed of the reel, however, is objectionable as it reduces the viscosity and tends to cause a grainy condition of the finished product. The proper number of revolutions of the reel necessarily varies with the size of the sterilizer, ranging from about 6 to 12 R.P.M.

Loading the Sterilizer.—In the case of sterilizers with spider can carriage the hermetically sealed cans are placed in iron trays holding 24—14½ oz. cans, or 6—1 gallon cans. These trays are slid and locked into the spider frame in the interior of the sterilizer. The sterilizer door or doors are closed and the reel is put in motion. In the case of sterilizers with crate carriage, the cans are stacked into the crate and the crate is locked to keep the cans in place.

Uniform Distribution of Heat in the Sterilizer.—Successful sterilization demands uniform distribution of heat. The cans in all parts of the sterilizer must be subjected to the same temperature for the same length of time. This is important, as faulty heat distribution tends to destroy the uniformity of consistency and color throughout the batch and is prone to increase the per cent of cans "going wrong" because of incomplete sterilization.

The proper heat distribution in the sterilizer is largely controlled by the type and condition of the steam distributing device. The steam is distributed in the sterilizer through a perforated pipe running from end to end in the bottom of the sterilizer. A satisfactory arrangement that will insure uniform steam distribution is shown in Fig. 81. The steam line is brought to the center under the sterilizer, from there one lateral extends in each direction, entering the sterilizer both at the front and at the rear. A perforated pipe inside of the sterilizer connects with the steam intake at each end.

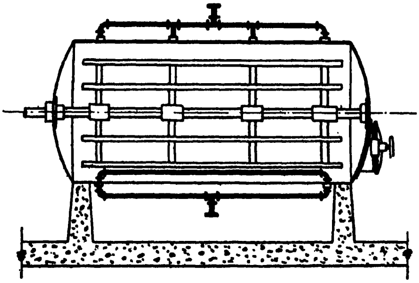

Fig. 81. Arrangement of steam supply for uniform heat distribution in batch sterilizer

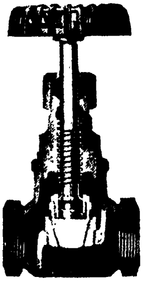

Fig. 82. The Hancock non-leak steam valve
Courtesy of Consolidated Ashcroft Hancock Co.

The condition of the perforated steam-distributing pipes themselves must be right. The perforations must be of uniform size. In the case of thin brass pipe, they soon become enlarged due to the wearing action of the steam. In the case of iron pipe, rusting further hastens such enlargement. Occasionally it happens that the cap at the end of the perforated pipe comes off. Such a situation makes uniform distribution of steam in the sterilizer impossible. The perforated steam distributing pipes should therefore be examined by the operator each day before the sterilizer is loaded and should be kept in proper condition for operation.

The cans should be spaced properly in the sterilizer, so as to facilitate efficient circulation of the heating medium and uniform transmission of heat to the cans in all parts of the retort.

It is advisable to establish the efficiency of heat distribution in the sterilizer by accurate test. For this purpose the use of cans equipped with "tell-tale" thermometers, similar to medical thermometers, but registering sterilizing temperatures, may be found helpful. Such cans are placed in different parts in the cages of the sterilizer at the time the sterilizer is loaded, and at the conclusion of the process these thermometers indicate the maximum temperature to which the contents of the respective cans were heated.

Another, very simple and reliable method of testing the sterilizer for heat distribution, is to test numerous cans from different parts of the sterilizer, after sterilization, for viscosity by means of the Mojonnier viscosimeter or similar device, as described under "Testing Sample Cans for Viscosity," see Chapter XVI.

Adding Water to Sterilizer.—Uniform heat transmission is enhanced by the use of water in the sterilizer. Water also hastens the heating during the "coming up" period and it eliminates air pockets between the cans. It is best to use just enough water so that all the cans in one position of the reel are submerged. In this way each can is covered by the water once with every revolution of the reel. Fuel may be economized by storing the hot water between sterilizer batches. While the use of water in the sterilizer assists in uniform heat distribution it will give the best results only when the other necessary requirements are also provided. Uniform steam distribution and proper spacing of cans are necessary when sterilizing in the presence as well as in the absence of water.

Starting the Sterilizer.—The loaded sterilizer is now closed.

The reel is set in motion. Hot water is drawn in and the steam is turned on. In order to expel the air and to hasten the heating, the steam exhaust is left open until the temperature approaches 200 to 212° F. Then it is closed and the temperature is raised to that which will insure complete sterilization.

Temperature and Time of Exposure.—From this point on, the process must depend on locality, season of year, condition, properties and concentration of the milk, treatment which the milk received prior to sterilization, and type of sterilizer. No formula can be laid down which can be depended on to give uniformly satisfactory results under all conditions. Nor does the proper sterilization depend on one particular formula. There are numerous ratios of temperature, time of exposure and extent of agitation which, when adjusted to local conditions, may give satisfactory results. The temperature should be high enough and the duration of exposure long enough to insure absolute sterility of the product and to give the milk sufficient body to prevent the separation of the butterfat in subsequent storage. The temperature should not be so high nor the duration of exposure so long, as to cause the formation of a hard, unshakable curd and dark color. From the standpoint of flavor and color a relatively short process with high maximum temperature is preferable, but such milk generally lacks the viscosity necessary to keep the fat from separating out in subsequent storage, unless the milk has been properly homogenized.

It is now conceded by the great majority of experienced evaporated milk manufacturers, that for best sterilizing practice where the batch sterilizer is used, the "coming up" time, i. e., raising the temperature from room temperature to 240° F. should not be less than 15 minutes nor more than 20 minutes, the best results being secured in 15 minutes when using water in the sterilizer, or in 20 minutes when using "live" steam only. It is further recommended that the rise in temperature during the last 10 minutes of "coming up" time should be at the rate of 5° F. for every minute, that the temperature of holding be not lower than 240° F. and not higher than 245° F. and the time of holding at 240° F. not less than 15 minutes.

The stopping of the reel during the holding period is now a common practice. Its advantage is that it diminishes the tendency toward a grainy product and it enhances the formation of a very soft, custard-like coagulum that shakes down readily and completely and gives the evaporated milk a rich, creamy appearance.

The installation and efficient use of automatic temperature controllers and recorders is of material assistance for securing uniform results of sterilization. These accessories are made use of in numerous factories, and have proven to be of valuable help to the manufacturer.

Heat Required for Different Size Cans.—The size of the can has some effect on the sterilizing efficiency. Large size cans sterilize somewhat more difficultly than small size cans. It is not an uncommon experience that the per cent loss due to spoilage of gallon cans is greater than that of family and baby size cans. For this reason the practice in many condenseries is to give gallon batches at least one degree F. more heat during the holding time than tall-size cans, and tall-size cans at least one degree F. more than baby-size cans.

Cooling After Sterilization.—Immediately after the holding time the evaporated milk is cooled. The steam is turned off, exhaust and drain are opened and cold water is turned into the sterilizer with the reel revolving and the cooling is continued until the temperature of the milk has dropped to 70 to 80° F. It should not take more than 15 minutes to cool the milk. Gallon cans cool somewhat slower than small size cans. Rapid and uniform cooling is important. This requires a plentiful supply of cold water and proper distribution of the water over the entire length of the sterilizer.

Insufficient water supply and uneven distribution of the water in the sterilizer exposes some of the cans to the sterilizing heat longer than others, causing lack of uniformity in the smoothness and color of the milk of different cans of the same batch. Delayed cooling, owing to insufficient water supply has the further disadvantage of causing the cans to bulge badly, owing to the difference in pressure between the interior and exterior of the cans. This is especially noticeable in gallon-size cans, the ends of which may become distorted, and their seams and seals may be weakened to the extent of producing "leakers." Excessive bulging and injury to the cans can be avoided by admitting to the sterilizer a sufficient quantity of compressed air to take the place of the released steam pressure, thereby equalizing the pressure between the outside and inside of the cans during the cooling process.

Fractional Sterilization.—In the early days of the manufacture of evaporated milk the product was sterilized by fractional sterilization. This method has now been largely abandoned, but is occasionally used when the milk happens to be in very abnormal condition. The milk is heated in the sterilizer to considerably lower temperatures than those stated above, and this heating is repeated on two or three successive days. The principle of this process is to kill all vegetative forms of bacteria during the first heating. This gives the spores a chance to develop into vegetative forms by the second and third days, which forms are then destroyed during subsequent heating.

Fractional sterilization, or "Double Cooking" may be helpful also in cases where the troublesome heat coagulation is due mainly to a high albumin content and where adjustment of the salt balance, therefore, fails to raise the coagulation point of the evaporated milk to the level of a safe sterilizing temperature, as suggested by Sommer and Hart.[60] Fractional sterilization, however, is no longer considered commercially practicable. Except in isolated cases it has become obsolete.

SHAKING

Purpose.—The purpose of shaking evaporated milk after sterilization is to mechanically break down the curd that may have been formed during the process of sterilization, and to give the contents of the cans a smooth and homogeneous texture.

As explained in previous paragraphs, the heat coagulation point of evaporated milk is affected by many factors, some of which are ever-changing, and even apparently minute changes often influence heat stability to a marked degree. Efforts to carefully standardize the properties of milk that control heat coagulation and the systematic use of a standard sterilizing process are of material assistance in preventing the appearance of curd of a nature that requires mechanical shaking in order to reduce the product to the desired smoothness. Yet, the control of curd formation in the sterilizer is not as yet so complete as to justify the elimination of the process of shaking under all conditions of milk and methods of manufacture.

Method of Shaking.—The shaker consists of one or more heavy iron boxes or iron crates usually made of black iron pipes. These boxes are attached to an eccentric. The trays filled with evaporated milk cans are firmly wedged into these boxes. When the shaker is in operation, the cans are shaken back and forth violently, causing the curd in the cans to disintegrate.

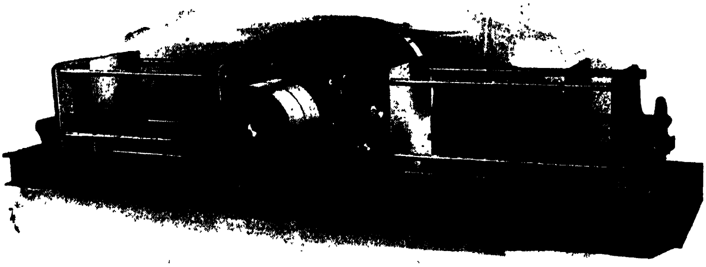

Fig. 83. The Berlin evaporated milk shaker
Courtesy of Berlin-Chapman Co.

Amount of Shaking.—From one-fourth to two minutes' shaking is usually sufficient to completely break down a soft curd. When shaking for five minutes does not produce a smooth milk, the product is usually hopelessly curdy and no amount of additional shaking will remedy the defect. In some cases it has been possible, however, to improve the curdy product by shaking again after a day or two. Under certain conditions, age seems to have a slight mellowing effect on the curd.

When the coagulum in the evaporated milk is soft, as it should be, shaking for one-fourth to one-half minute is usually sufficient to reduce the contents of the cans to a smooth and homogeneous consistency. When the curd produced is firm, even prolonged shaking will not prevent the appearance in the finished product of specks and small lumps of curd.

The formation of curd during the sterilizing process is not desirable and is not necessary as far as the marketable properties of the evaporated milk are concerned. It is unavoidable, however, under many conditions and as long as it can be confined to a soft curd that readily shakes out, no harm is done.

The shaking reduces the viscosity of evaporated milk. Excessive shaking makes the milk too thin and should therefore be avoided. The danger of destroying viscosity is greatest when shaking at a high temperature. Evaporated milk should be shaken at ordinary temperatures.

Incubating.—From the shaker the cans are transferred to the incubating or storage room where the trays containing them are stacked. Most factories practice a system of holding their batches of evaporated milk from 10 to 30 days. The purpose of holding or incubating is to detect defective milk or defective cans before the goods are released for the market.

The temperature of incubation varies. In most plants no special effort is made to regulate the temperature, and the milk is held at ordinary room temperature. In other factories special incubating rooms are provided for holding the milk at somewhat higher temperatures, usually from about 80 to 97° F. The great majority of bacteria causing spoilage in evaporated milk are most active at the higher temperatures. This includes the lactic acid, gas producing and many other types. The detection of spoils or prospective spoils is therefore expedited by using the higher temperatures.

However, prolonged storage of evaporated milk at these higher temperatures does not improve the product and may damage it physically. It tends to darken the color, destroy the viscosity, and invite excessive precipitation of calcium citrate under certain conditions. For these reasons the lower temperatures of incubation are preferable. The spoilage may be due to bacterial, chemical or physical causes. These defects and their prevention are discussed in detail in Chapter XXVI on "Defective Evaporated Milk."

CHAPTER XV

FACTORS THAT INFLUENCE THE HEAT COAGULATION OF MILK

The successful control of the behavior of evaporated milk in the sterilizer and the satisfactory use of a standardized sterilizing process depend in a large measure on an intelligent understanding of the factors that influence the heat coagulation of milk. Within the last decade this problem has been subjected to extensive and careful study by some of the foremost research workers in the field of dairy science. These labors have been fruitful of interesting discoveries of the properties of milk and their relation to heat coagulation, the practical application of which is proving of great value to the industry.

EFFECT OF ACIDITY ON HEAT COAGULATION OF MILK

Acidity Lowers the Heat Coagulation Point.—It is well known that sour milk curdles when heated. The higher the acidity the lower the temperature required to curdle the milk. McInerney[70] conducted a series of tests with fluid milk soured to acidities ranging from .25% to .58%. He showed that, in the case of the milk he used, the temperature of heat coagulation at an acidity of .25% was 185° F. The heat coagulation temperature decreased as the acidity increased. At an acidity of .56% to .58% the milk coagulated at between 60 and 70° F.

Heating Tends to Increase the Acidity of Milk.—There is a slight increase in the acid reaction of the milk due to the heat employed in the process of manufacture. The effect of heat on the acidity of milk has been studied by Kirsten,[71] Orla-Jensen and Plattner,[72] Van Dam,[73] Milroy,[74] Ducombe,[75] Cosmovici,[76] Sharp and McInerney,[77] Whittier and Benton,[78, 79] and Hunziker, Cordes and Nissen.[80] The results may be summarized as follows: The heating of milk to or near the boiling point causes first a drop and then a rise in the titratable acidity. The initial drop in titratable acidity is due to expulsion of carbon dioxide from the milk. The heating of milk causes the hydrogen ion concentration to increase continuously. The increase in titratable acidity and in hydrogen ion concentration is attributed to the formation of acids from certain milk constituents. Orla-Jensen and Plattner hold this increase of acid to come largely from the casein and to a lesser extent from the lactose. Whittier and Benton, on the other hand, show that the lactose is the principal source of the acid produced by the heating of milk.

Concentration of Evaporated Milk Increases Acidity.—In the manufacture of evaporated milk the curdling effect of the acid present is intensified by the increased concentration. The condensing of the milk increases both the titratable acidity and the hydrogen ion concentration. The titratable acidity of evaporated milk before sterilization is usually slightly greater than that of the corresponding fluid milk prior to condensing, times the ratio of concentration. The hydrogen ion concentration also shows a continuous increase due to evaporation. In the fresh milk it falls within the range of about pH 6.5 to pH 6.68, while in the evaporated milk its usual range is within the limits of approximately pH 6.15 to pH 6.3.

Sources of Acid in Milk.—The milk derives its acid reaction chiefly from two separate and distinct sources, and according to source the acidity is known as "natural" or "apparent" acidity, and as "developed" acidity. The effect of the acid reaction on the heat stability of the milk depends on the type or source of acidity present.

The "Natural" or "Apparent" Acidity.—This is the acidity that is inherent in milk at the time it is drawn. It represents the acid reaction of some of the constitutents of milk. The "natural" acidity of milk has been the subject of study by many investigators. Their findings and conclusions as to its source are not altogether in agreement, but the bulk of experimental data points to the casein as one of the major sources. Rice and Markley[81] studied the natural acidity in freshly drawn milk and accounted for it as follows:

Carbon dioxide, in amount equivalent to .01 to .02% lactic acid.
Citric acid, in amount equivalent to .01% lactic acid.
Albumin, in amount equivalent to .01% lactic acid.
Casein, in amount equivalent to .05 to .08% lactic acid.
Phosphates, in amount equivalent to the difference between

the total natural acidity and that due to the sum of the above enumerated factors.

The percentage of natural acidity has been found to vary considerably and the range of variations reported by different experimenters differs somewhat. In the case of milk from individual cows the extreme variations have been found to range from .086 to .275 per cent natural acidity. These extreme variations are rare exceptions, however, and especially in mixed herd milk, the natural acidity runs quite uniform. Thus Fleming and Nair[82] studied the acidity of milk from 766 herds representing 7700 cows. They found the natural acidity of the fresh milk from individual cows to range from .10 to .175 per cent. The average was .136 per cent.

The percentage of natural acidity appears to vary chiefly with the percentage of solids not fat in milk. Rice and Markley demonstrated that milk with a high natural acidity is also richer in solids not fat. These observations are confirmed by the earlier results of McInerney[70] who found that, while neither age of cow, period of lactation, nor character of feed had any noticeable effect on the natural acidity of milk, fresh milk which showed a high percentage of solids not fat and of ash, also showed a high percentage of natural acid. Fresh milk comparatively low in solids not fat and in ash showed a lower percentage of natural acidity.

The natural acidity of milk does not lower the heat coagulation point. On this question investigators appear to be unanimous. Sommer and Hart,[83] Rogers, Deysher and Evans,[33] Rice and Markley,[81] and others arrived at this conclusion after most comprehensive study of the subject. Rice and Markley further showed that milk with a high natural acidity generally reaches the heat coagulation point later than milk with a low natural acidity.

The "Developed" Acidity.—This is the acidity present in milk in excess of the natural acidity. The developed acid usually represents the acid produced by fermentation after the milk has been drawn. When the milk arrives at the factory it may, and often does, contain some developed acidity. The heat coagulation point is exceedingly sensitive to the developed acidity. Even a small increase in total acidity above the natural acidity of the same milk is capable of lowering the heat coagulation point. This was clearly shown by Rogers, Deysher and Evans[33] whose results are summarized in Table 14.

Table 14.—Influence of the Growth of Acid-Forming Bacteria on the Coagulating Temperature of Evaporated Milk.

Age Hrs.	Bacteria in Raw Milk		Titratable Acidity per cent	Hydrogen ion Concentration		Coagulation Temperature	
	Total per cc.	Lactic per cc.		Raw	Evaporated	° C.	° F.
0	1,140,000	790,000	.17	6.57	6.33	119	246.2
3	47,500,000	30,500,000	.175	6.51	6.27	113	235.4
4½	96,000,000	53,500,000	.207	6.43	6.21	110	230.0

Holm, Deysher and Evans,[57] in additional experiments, obtained similar results. They found that evaporated milk made from milk that had been held at about 18° C. (64.4° F.) for twenty-four hours had a decidedly lower coagulation temperature than lots from the same milk when fresh. The heat coagulation point of the held milk was from 20 to 25° F. lower than that of the milk that was condensed while fresh; and they suggest that "this change in the inferior milk (the milk that had been held) was undoubtedly caused largely by acid-forming bacteria."

The grading of milk on the basis of its titratable acidity, therefore, cannot be considered an infallible guide as to the fitness of milk as far as its acid content is concerned. This fact detracts somewhat from the value for manufacturing purposes and from the justice to the milk producer, of the adoption and inflexible use of an acid standard. This, together with the fact now well understood that the titratable acidity is not the only factor and perhaps not even one of the most important factors bearing on the fitness of milk from the standpoint of heat coagulation, has brought some severe criticism upon the practice of accepting milk on the basis of the acid test.

This is unfortunate as it tends to confuse the issue. The acid test has distinct merits. In most cases of high acid milk the high acidity is due to developed acid. Milk with a high natural acidity is a rare exception. Only in isolated cases does the milk show a natural acidity of .18 per cent or more. In mixed herd milk such occurrence is still more remote. It is largely only when milk has not been handled properly on the farm that the acidity reaches or exceeds the limit of .18 per cent. In such cases it is not the natural acidity but the developed acidity that causes the high per cent of titratable acid. As a rule the nose and palate of the inspector will find such milk suspicious and the acid test is made for confirmation. The acid test is not an all embracing and infallible detection of conditions that influence the behavior of evaporated milk in the sterilizer, but it may well be looked upon as a dependable answer concerning the fitness of the milk in so far as the acidity is a factor in the lowering of the heat coagulation point.

It is wisdom on the part of the condensery to adopt a maximum acid limit for its fluid milk. A limit of .18 per cent acid has been found suitable for condensery purposes.

Aside from the direct effect on heat stability, of even a small change in the acid reaction caused by developed acidity, as shown above, the effect may be indirect. Sommer and Hart[69] point out that acid fermentation tends to destroy the citric acid in milk. This in turn would cause an excess of available calcium. Excess of available calcium disturbs the calcium-casein balance of milk, and this condition is believed to be one of the dominant causes of heat coagulation difficulties, as will be shown later in this chapter under "Effect of Mineral Salts on Heat Coagulation."

The Titratable Acidity.—This represents the number of cubic centimeters of decinormal alkali (usually sodium hydroxide) required to make a known amount of sample of milk neutral to phenolphthalein. It is usually expressed in terms of per cent lactic acid. The titratable acidity does not show the developed acid as such, it gives the total acidity made up of both the natural and the developed acids. In the case of the milk received at the condensery a relatively large proportion of the total acid is natural acidity which does not materially affect the heat coagulation point.

The True Acidity or pH Value.—The true acidity is based on the concentration of hydrogen ions. The acid principle of all acid solutions depends on the presence of hydrogen ions.

The hydrogen ion concentration expresses the degree of ionization of the acids present. In the presence of electric current acid molecules in solution dissociate into positive hydrogen ions, and negative ions representing the remainder of the molecule. It is the number of these hydrogen ions so determined which constitutes the hydrogen ion concentration, or C_H.

The hydrogen ion concentration is usually not expressed in terms of a normal solution of C_H, however. It is expressed by the symbol pH. This is a technical term which has come to mean the exponent of ten with a negative sign which expresses the concentration in gram-ions of hydrogen per liter. The letters "p" and "H" have no meaning when separated. The symbol pH is merely an arbitrary technical definition which is used instead of C_H because of its greater convenience. It avoids the cumbersome use of a large number of decimals. The following example may serve to illustrate the point:

Pure water, which is considered neutral, has a hydrogen ion concentration, or C_H value, of 1×10^{-7} or .000,000.1. In order to avoid this long figure the logarithm of the reciprocal of this figure is taken. In the case of the above example this gives the figure 7.0, which is used in the pH scale as the neutral point. Pure water has a pH value of 7. Assuming now that the hydrogen ion concentration is increased to ten times that of pure water, the C_H would be 1×10^{-6}, or .000,001. The logarithm of the reciprocal of this figure then would give the figure 6. In this case the pH value would be 6. From these brief examples it may be seen that, as the true acidity or the hydrogen ion concentration increases, the pH value decreases.

The relation of the hydrogen ion concentration to the heat stability of milk has been studied by Sommer and Hart,[83, 84, 69] Rogers, Deysher and Evans,[33] Rice and Markley,[81] Benton and Albery,[85] Webb,[86] Webb and Holm,[87] and Holm, Webb and Deysher.[88] While the results and conclusions of these investigators show divergencies in details, their findings do establish the general fact that the hydrogen ion concentration alone is not a dependable index to the heat stability of the evaporated product.

The uncertainty of the effect of the hydrogen ion concentration on the heat coagulation point is attributed, in part at least, to the presence of buffer substances in milk, such as proteins, phosphates, citrates and carbonates, which affect the results of the determination of the hydrogen ion concentration. A buffer is a substance which tends to prevent change of the original hydrogen ion concentration in its solution when an acid or an alkali is added. In the case of milk the development of acid due to bacterial activity constitutes addition of acid. The extent or intensity of buffer activity varies with the concentration of buffers present, original acidity, temperature, and other factors. Rice and Markley showed that the proportion of such buffer substances as casein and phosphates is greater in milk of high natural acidity, and it is the influence of these substances acting as buffers that minimizes the change in the true acidity of high-acid milk. These authors emphasize the significance of strong buffer action in high acid milk in the consideration of lactic acid acidity due to bacterial development. They show that here it is necessary that a larger amount of acid be produced to change the pH value than in low-acid milk; and they conclude that differences in the hydrogen ion concentration would not be as sensitive a means of determining the degree of souring as titration figures.

Rogers and co-workers likewise observed a consistent lack of any definite relation between hydrogen ion concentration and heat coagulation temperature. Their results show that any increase from the normal hydrogen ion concentration of milk causes a distinct lowering of the heat coagulation point after condensing, although the final hydrogen ion concentration may still be considerably under that of another sample which is comparatively stable. They, therefore, conclude that "the essential fact which must be established is not the mere hydrogen ion concentration of the milk, but whether this has been changed from the normal of that particular milk."

The above conclusions are supported by the work of Benton and Albery who found the milk from individual cows to vary considerably in pH and in resistance to heat coagulation from day to day. Their results show that the pH effect may completely overshadow any action of buffer solutions, especially if the sample lies above or below a pH range of about 6.58 to 6.65. Within this range changes in the salt balance appeared very important; outside of it changes in pH produced a more marked effect. These authors conclude that each sample of milk, whether mixed or from a single cow, must be regarded as a separate colloidal system and that "for each milk there is an optimum combination of pH and salt balance, which will yield maximum stability. This optimum is probably the resultant of several variables and, consequently, is an expression of the colloidal peculiarities of the particular sample."

The work of Webb who studied the effect of mixing different grades of raw milk on heat stability further confirms the conclusions of Benton and Albery. He observed that the addition of small amounts of milk of poor quality to larger amounts of good milk produced an evaporated milk of uncertain stability. In some cases the mixing of grades improved, in others it diminished the heat stability of the resulting evaporated milk. He ascribes the change in heat stability, observed as the result of mixing different grades, or of adding acid, or of aging the milk, to the accompanying change in the hydrogen ion concentration. Webb was able to secure identical results in heat coagulation by mixing milks of different quality as by aging a single sample.

Holm and co-workers[88] made an extensive study of the various properties of milk as related to heat stability. Their experiments were conducted with milk from four individual cows, using samples at regular intervals during the entire period of lactation of each cow. Their results show no consistent relation between hydrogen ion concentration and heat coagulation temperature, and they conclude that their findings emphasize the conclusions of Benton and Albery.

Variations of Effect of Acid Reaction on Heat Stability.—An increase in acid does not necessarily always lower the heat coagulation point, and under certain conditions it will even have a definite stabilizing effect on the milk. Thus Sommer and Hart[69] were able to raise the heat coagulation point of some milks by the addition of acid. They attribute these exceptional occurrences to milk that lacks heat stability because of a deficiency of calcium or magnesium (excess of citrates and phosphates). Such milk is improved by a slight increase in acidity because the increased acidity changes secondary to primary phosphates. Since the primary phosphates have little or no effect on the salt balance, this change diminishes the amount of phosphate that ties up calcium; more calcium is available to satisfy the calcium-casein balance; it has the same effect as removing some of the phosphates or adding soluble calcium salts. In such cases, therefore, a slight increase in acid improves the calcium-casein balance and raises the heat coagulation point.

Instances of this calcium-deficient milk do occur. They have been found in milk from individual cows, but such cases are the exception. The prevailing tendency for mixed herd milk such as is received at the condensery, is to show an excess of calcium and to be deficient in phosphates and citrates, conditions which would cause an increased acidity to intensify its sensitiveness toward heat and to lower its heat stability. Similar observations were made by Webb and Holm.[87]

Summary of Effect of Acid Reaction on Heat Stability of Milk.—1. Milk contains both natural (apparent) acidity and developed acidity.

2. The natural acidity does not lower the heat coagulation point.

3. Even a small increase in developed acidity is capable of materially diminishing the heat stability of milk.

4. The titratable acidity represents both the natural and developed acidity calculated as lactic acid. The acid titration test on the milk receiving platform is therefore of limited value only as a guide to heat stability.

5. The hydrogen ion concentration of milk has a marked effect on heat stability.

6. The optimum acid reaction for maximum heat stability is dependent on its relation to the salt balance and to other variables of milk. It may fluctuate, therefore, over a considerable range.

7. Each lot of milk has its own optimum combination of acid reaction, salt balance and other variables for maximum heat stability.

8. Each lot of milk, therefore, has its own optimum acid reaction which may or may not apply to any other lot of milk.

9. In general, an increase in the acid reaction above normal (or a decrease in pH below normal) for a given lot of milk will be accompanied by diminished heat stability.

10. It appears not feasible, therefore, to establish a standard optimum acid reaction or pH value of milk for factory use, as a dependable control of heat stability of the evaporated milk in the sterilizer.

11. On account of interfering buffer effects, differences in the hydrogen ion concentration would, in many cases, not supply as sensitive a means of determining the degree of souring as the acid titration figures.

Effect of Products of Bacterial Origin Other Than Acidity on Heat Coagulation of Milk.—Bacterial contamination of the milk may lower the heat coagulation point of evaporated milk through activities other than acid formation. Certain species of bacteria produce rennet and rennet-like enzymes. Heavy contamination with this type of organisms is capable of lowering the heat coagulation temperature.

Rogers[89] inoculated milk with rennet-forming bacteria and held it at room temperature for three hours. After condensing, the milk was sterilized His results show that the inoculated milk coagulated at 226° F., while the control samples coagulated at 240.4° F. Frazier[90] also showed that sweet-curdling bacteria, when present in considerable numbers, will hasten the heat coagulation of milk and that the addition of a culture of sweet-curdling bacteria lowers the acidity at which heat coagulation will take place.

These data, while limited in scope, indicate unmistakably that profuse contamination of the milk with microorganisms capable of forming rennet and rennet-like enzymes diminishes its heat stability. Under normal conditions of production and handling of the milk on the farm, the presence of this type of germs in large numbers is rare and heat coagulation difficulties from this source are exceptional. Yet the possibility is ever present and should not be overlooked when the milk behaves abnormally in the sterilizer.

Rennet-forming organisms are usually closely associated with insanitary conditions in the care and handling of the milk. Unclean milk utensils on the farm, such as rubber tubes and other parts of the milking machine, milk pails, cloth strainers and milk cans may become prolific sources of this kind of contamination. Insanitary equipment in the factory itself is also potent with possibilities for such contamination. This refers especially to such equipment as the filling machines, milk pumps and pipes, agitator shafts and bearings submerged in the milk, etc. The price of freedom from sterilizing difficulties that are due to bacterial contamination is eternal vigilance in attention to the multitude of details that make for scrupulous cleanliness, both in the production of milk on the farm and in its care in every department in the factory.

EFFECT OF ALBUMIN AND CASEIN ON HEAT COAGULATION

The nitrogenous constitutents of the milk are the true cause of heat coagulation. It is they that heat coagulation refers to. They are the substances that are being coagulated. All other ingredients or factors influencing heat coagulation of milk are important only in so far as they affect the sensitiveness of the proteins of milk toward heat. The most important nitrogenous substances in milk are the casein and the albumin. Both are coagulated by heat.

The casein is of primary importance. It represents about 80 per cent of the total nitrogenous matter in milk. It is coagulated by weak acid and by rennet. In sour milk containing from .55 to .60 per cent acid it coagulates at ordinary temperature (60 to 70° F.). In fresh milk it coagulates with heat under pressure at a temperature of about 268 to 280° F., but even at pasteurizing temperatures it loses its power to react normally toward rennet. The condensing of milk lowers the heat coagulation point of the casein. The stability of the casein toward heat is very greatly influenced by the balance of mineral salts in milk, as discussed under the heading "Effect of Mineral Salts on Heat Coagulation," later in this chapter.

The albumin of milk is present to the extent of about 15 per cent of the milk proteins. It is partly coagulated by heat in normal milk, and completely in the presence of an acid medium. It is not affected by rennet, nor by acid at ordinary temperature, nor by the mineral constituents of milk, as shown by Osborne and Wakeman.[91]

That the milk albumin is a factor in heat coagulation is shown by Rogers, Deysher and Evans,[64] who determined its effect on the viscosity of sweetened condensed milk. They report that "when the forewarming temperature was above 90° C. (194° F.) the initial viscosity and the increased viscosity were in direct relation to the amount of albumin added. On the other hand, when the forewarming temperature was held below 60° C. (140° F.) the initial viscosity was the same for all lots and the changes, which were small, had no relation to the albumin content of milk.

The data cited show that the albumin content of milk is a factor in the heat coagulation of evaporated milk. Sommer and Hart[69] consider the importance of this factor secondary only to the salt balance. They suggest that troublesome heat coagulation resulting from abnormally high albumin content may be materially minimized by the practice of "double cooking." See "Superheating," Chapter XII. Because of the higher acid reaction in the concentrated milk and the heating of this concentrated milk to temperatures higher than pan temperature, an additional fraction of the albumin is coagulated. This jell is completely broken up by subsequent boiling in the pan and further by homogenizing, thus eliminating a larger portion of the albumin content of the milk from jell formation in the sterilizer.

Sommer[92] demonstrated experimentally that even a small increase in the albumin content caused a considerable decrease in the time of sterilization required to coagulate the milk. He divided a sample of milk containing .67 per cent albumin into two portions. One portion was used as control, to the other was added .09 per cent lact-albumin. Both lots were preheated at the boiling point for five minutes and then condensed and standardized to 18 per cent solids not fat. In the pilot sterilizer the control lot coagulated at 245° F. in 20 minutes and the sample to which albumin had been added, in 15 minutes.

In a further experiment Sommer showed that the effect of preheating on the heat coagulation point of milk is due in part at least to the precipitation of the albumin. In this case he found that the sample of milk preheated at 180° F. contained .86 per cent soluble albumin, while another sample of the same milk, preheated at the boiling point, contained only .56 per cent soluble albumin. The 180° F. preheated sample coagulated at 245° F. in eleven minutes, while the sample preheated at the boiling point required twenty minutes for coagulation. Sommer therefore concludes that the effect of preheating is largely due to the precipitation of the albumin.

Both the casein and the albumin content of milk vary with the season of the year. These variations are largely caused by changes in the period of lactation of the cows. The variations are somewhat greater in the case of albumin than with casein, as shown by Eckles and Shaw[93] and by Hunziker.[94] Hunziker's results are shown in Table 15. This tables gives the albumin and casein content of milk from three individual cows over an entire lactation period.

Table 15.—Effect of Period of Lactation on the Percentages of Albumin, Casein and Total Proteids in the Milk of Three Cows

Period of Lactation	Cow No. 1			Cow No. 2			Cow No. 3		
	Albumin	Casein	Total Proteids	Albumin	Casein	Total Proteids	Albumin	Casein	Total Proteids
First 14 milkings......	.98	3.18	4.16	1.59	3.81	5.40	1.72	4.46	6.18
1 st month..........	.57	2.55	3.12	.55	2.47	3.02	.58	2.88	3.40
2nd month..........	.53	2.27	2.80	.47	2.37	2.84	.51	3 06	3 57
3rd month..........	.52	2.54	3 06	.48	2 28	2.76	.55	3 25	3.80
4th month..........	.56	2.51	3.07	.50	2 36	2.86	.60	3.05	3.65
5th month..........	.55	2.62	3.17	.48	2.26	2.74	.60	3.05	3 65
6th month..........	.53	2.65	3.18	.54	2.30	2.84	.73	2 96	3.69
7th month..........	.86	2.62	3.48	.76	2 50	3.26	.62	2.99	3.61
8th month..........	.75	2.79	3.54	.60	2.66	3.26	.64	2.94	3.58
9th month..........	.73	2.84	3.57	.56	2.73	3.29	.72	3.30	4 02
10th month..........	.77	3.02	2.79	.59	2.73	3.32	.82	3.39	4.21
11th month..........	.91	3.08	3.99	.61	2.88	3.49	....	....	....

Table 15 shows that at the beginning and toward the end of the period of lactation the casein and especially the albumin content of milk is highest. Colostrum milk and milk from stripper cows therefore would tend to lower the heat coagulation. This is borne out in the manufacture of evaporated milk by the general experience that heat coagulation difficulties are greatest in Fall and in early Spring when most of the cows either are far advanced in their period of lactation or have freshened. Rigorous inspection of the milk on the platform and efficient control over the milk supply are helpful safeguards against the acceptance of milk distinctly abnormal in this respect. This, together with the intelligent adjustment of the forewarming temperature, which is discussed later in this chapter, should be of material aid in efforts to avoid serious sterilizing difficulties resulting from causes of this nature.

EFFECT OF MINERAL SALTS ON HEAT COAGULATION POINT

The temperature at which evaporated milk curdles in the sterilizer is very greatly affected and to a large extent controlled by the balance of the milk salts. This fact has been known by the industry in a general way for many years but the science of the relation of milk salts to heat coagulation was not well understood. Until the introduction of the Mojonnier Method of Evaporated Milk Control in 1916, no systematic method of preventing heat coagulation difficulties was available to the industry as a whole, though the scientific research laboratories of some of the larger evaporated milk concerns may have developed such methods for their own use. Timothy Mojonnier's comprehensive researches covering an extended and careful study resulted in the development of the systematic use of bicarbonate of soda as a means of standardizing the coagulation point of evaporated milk. This, together with the use of the pilot sterilizer and viscosimeter, has been of great help to the industry. The Mojonnier Method will be further described in Chapter XVI.

Later extensive study of the science of heat coagulation and of the relation of the mineral salts of milk to heat stability by Sommer and Hart,[83, 84, 92, 09] Rogers, Deysher and Evans,[33] Benton and Albery,[85] Webb,[86] Holm, Webb and Deysher,[88] and Webb and Holm[87] has added much to our knowledge on this subject.

Sommer and Hart's Theory of the Salt Balance.—Sommer and Hart were the first investigators to demonstrate that, aside from the effect of the albumin on heat stability, the heat coagulation point of milk is fundamentally controlled by the salt balance and that the influence of other factors, such as acid reaction and heat treatment in the process of manufacture, is dependent largely on their relation to and effect on the salt balance. These findings are fundamental and are therefore briefly summarized in the following paragraphs:

The main factor in the heat coagulation of fresh milk is the salt composition of the milk, especially the calcium, magnesium, citrate and phosphate content. The effect of the calcium and magnesium salts is opposed to the effect of the citrates and phosphates and vice versa. An excess of either of these two classes of salts causes the milk to coagulate more readily; the proper balance produces the most stable condition.

The casein of the milk is most stable with regard to heat coagulation when it is in combination with a definite amount of calcium. If the calcium combination with the casein is above or below this optimum, the casein is not in its most stable condition. Thus the coagulation of a sample of milk on heating may be due either to an excess or a deficiency of calcium and magnesium. The calcium in the milk distributes itself between the casein, citrates, and phosphates chiefly.

The magnesium functions by replacing the calcium in the citrates and phosphates. If the milk is high in citrate and phosphate content, more calcium is necessary in order that the casein may retain its optimum calcium content after competing with the citrates and phosphates. In such case, low heat coagulation can be prevented by the addition of the proper amount of soluble calcium or magnesium salts. If the milk is high in calcium, there may not be sufficient citrate and phosphate to compete with the casein to lower its calcium content to the optimum casein-calcium balance. In such case, lack of heat stability can be prevented by the addition of the proper amount of citrates or phosphates in the form of sodium or potassium citrate or disodium phosphate.

In most cases the low heat coagulation is due to an excess of calcium and magnesium and can be prevented by addition of citrates, phosphates, carbonates and other salts. In observing the effect of additions of phosphates it was found that the secondary phosphate is the effective form of the phosphate in this salt balance. Primary phosphates were found to have little or no effect.

Sodium bicarbonate seems to have a two-fold effect on the heat coagulation. In milk samples that coagulate because of an excess of calcium, it prevents the coagulation; in samples that coagulate because of a deficiency of calcium, small additions of sodium bicarbonate hasten the coagulation, and larger additions prevent it. The addition of sodium bicarbonate changes some of the primary phosphate to secondary phosphate. As a result, samples that coagulate because of a lack of phosphate (excess of calcium) are improved by sodium bicarbonate, but samples that coagulate because of an excess of phosphate (lack of calcium) are injured by the addition of sodium bicarbonate because it increases this excess by changing primary to secondary phosphates. In the latter case larger additions of sodium bicarbonate prevent the coagulation, not by virtue of a salt balance, but because of the greatly reduced acidity, some of the sodium replacing calcium in the calcium-caseinate.

Experiments with milk samples and casein solutions prove that the salts concerned in the salt balance have a direct effect on the coagulation, and do not function by virtue of an indirect effect on the hydrogen ion concentration.

Milk samples that coagulate because of a lack of calcium (excess of citrates and phosphates) were found to be improved by a slight increase in acidity. The explanation is that the increase in acidity changes secondary phosphate to primary phosphate. The primary phosphates having little or no effect on the salt balance, cause this change to have the same effect as removing some of the phosphate or adding calcium.

The salt balance, which was found to affect the coagulation of fresh whole milk at 136° C, also affects the heat coagulation of evaporated milk at the lower temperature used in commercial sterilization. The knowledge of the salt balance gained by a study of fresh milk samples at 136° C. has been successfully applied in preventing troublesome coagulation of evaporated milk.

The reason there is no satisfactory agreement between the heat coagulation of the unconcentrated milk at 136° C., and the alcohol coagulation—even though all three are affected in a similar manner by the salt balance—is that when the milk is concentrated some of the salts are precipitated, the albumin is coagulated to a certain extent, and the hydrogen ion concentration is increased. This increase in the hydrogen ion concentration involves a change of secondary phosphate to primary phosphate.

Preheating of milk to boiling causes the milk to coagulate less readily than preheating to a lower temperature. The explanation is that the higher temperature precipitates a larger amount of the calcium salts and coagulates the albumin to a greater extent. In importance, the albumin is secondary only to the salt balance.

Later Findings of Effect of Salt Balance on Heat Coagulation.—Benton's and Albery's[85] results of experiments on the heat coagulation of milk are in general accord with Sommer and

Hart's findings; and they conclude that each lot of milk presents a separate colloidal system and that for each system there is an optimum combination of salt balance with such factors as pH, at which optimum the greatest heat stability is obtained. Webb[86] concludes that the deductions of Benton and Albery also apply to his results of experiments with mixtures of milks of different grades.

Rogers, Deysher and Evans[33] studied the effect of the salt balance (acid-base ratio) in mixed herd milk on heat coagulation analytically. They found no definite relation between the acid-base ratio, determined analytically, of the raw milk and the coagulating point of evaporated milk. Their conclusions are summarized as follows:

"The variation in the coagulation temperature of mixed herd milk is comparatively small and has little relation to the coagulating temperature of the same milk after evaporation. Consequently, the temperature at which evaporated milk made from the mixed milk of a number of cows will curdle cannot be predicted with any accuracy by determining the coagulation temperature of the raw milk.

"The interrelation of the constituents of the ash of the milk, which has been shown to be a factor in determining the coagulation point of fresh milk from individual cows, is only a minor factor in determining the coagulating temperature of evaporated milk. This is partly due to the rearrangement of the acid-base relation in the condensing process, and partly to the obscuring effect of other factors, which in the mixed milk from many cows become of much greater significance.

"The effect of high forewarming temperatures in raising the coagulating temperature of evaporated milk is evidently due to the precipitation of part of the calcium. Forewarming temperatures much below 95° C. (203° F.) have little effect on the coagulating temperature. The effect of high forewarming may be increased by prolonging the heating."

Holm, Webb and Deysher[88] investigated the relationship between the heat stability, composition and other properties of the milks of four cows during the course of an entire lactation period. Their results on salt balance corroborated the findings of Rogers and co-workers to the effect that the salt balance as determined by analysis of the milks showed no direct co-relation to the heat stability of the samples. They found, however, that "each of the individual milks for the most part retained fairly constant values in many of the tests, the values being characteristic of the milk of each cow." While they see in their results a "conclusive demonstration of the inadequacy of our present knowledge of the heat stability of milk," they hold that "the conclusions of Benton and Albery—that for each milk there is an optimum combination of pH and salt balance which will give maximum stability—is further demonstrated."

Leighton and Mudge[95] studied the endothermic (heat absorption) reaction which accompanies the appearance of a visible curd in milks coagulated by heat. Their results indicate that in heat coagulation of milk the calcium and magnesium of the milk are precipitated as phosphates and citrates, and that the reaction is endothermic. They also point out that the protein calcium is concerned in this reaction.

That the precipitation occurs with marked heat absorption at the moment of coagulation is further demonstrated by Leighton and Deysher[34] who applied the phenomenon in their efforts to determine the stability of condensed and evaporated milk by measuring the heat absorption and they conclude that, the greater the heat-resisting properties of milk, the less is the amount and speed of the precipitation of its calcium and magnesium as phosphates and citrates. They confirm in general, however, the conclusions by Rogers, Deysher and Evans on the uncertainty of the salt balance as the controlling factor in heat coagulation and conclude that "We cannot take Sommer's results as conclusive until we know a little more regarding the effect of the different ions upon the precipitation of casein."

The effect of ions other than calcium on the heat precipitation of casein was studied by Webb and Holm[87] who experimented with KCl, HCl, $BaCl_2$, $CaCl_2$, $AlCl_3$ and $ThCl_3$ added to skimmilks of different concentrations. Their results show that cations other than calcium have the same effect as the calcium ion and they therefore conclude that "the action of added calcium ions in changing the heat stability of a milk is not the result of the calcium itself, but rather of the positive charges which the ion carries; the effect of strongly positive cations being opposed to the action of heavy anions such as citrates and phosphates. They hold that there is a critical balance in the charge on the particle which is the criterion of maximum stability, and suggest that in the place of the term "salt balance," the necessary condition which must exist to secure maximum stability in a milk, could better be described as a "balance in particle charge."

Sommer's results, obtained in efforts to remedy troublesome heat coagulation on a commercial scale at a number of condenseries, showed that in no case was the coagulation of evaporated milk due to an excess of citrates or phosphates under natural conditions. This was conclusively proven by the fact that the addition to the milk of calcium or magnesium salts in all cases caused an increase rather than an improvement in the coagulation. On the other hand, the addition of sodium citrate or di-sodium phosphate did remedy the heat coagulation difficulties. Regarding the amount of these salts required to render sterilization safe, Sommer states:

"In general the addition of from 4 to 10 ounces of the crystalline di-sodium phosphate per 1,000 pounds of evaporated milk changed an unsafe sterilizing process to one that is satisfactory. In exceptional cases as high as one pound of di-sodium phosphate was added per 1,000 pounds of evaporated milk, but, on account of the large amount of water of crystallization in the di-sodium phosphate, this represents an increase of only 0.0198 per cent in the phosphoric acid content of evaporated milk. This addition on the basis of the unconcentrated milk amounts to only 0.0099 per cent, and is negligible when compared with the normal content of P_2O_5 and its normal variations in milk."

Sommer and Hart further point out that the effect of the salts is greater and more complete when they are added to the milk before concentration than after concentration. This is due to more thorough distribution and more complete action and interaction when they are present in the milk during the entire manufacturing process.

Summary on Effect of Salt Balance.—The above citations of results obtained and conclusions drawn by the several investigators in regard to the function and importance of the salt balance as related to troublesome heat coagulation emphasize the complexity of the subject of heat coagulation. While the interpretations of results reveal some divergences, the results themselves are not at all dissimilar. As far as their practical application is concerned they unmistakably support the following deductions:

1. The salt balance is one of the most important known phases in the combination of factors that control the heat stability of evaporated milk.

2. The casein is most stable when it is in combination with a definite amount of calcium. Excess or deficiency of calcium available for the casein-calcium combination lowers the heat stability of the casein. The calcium and magnesium ions represent the positive charges, and are therefore opposed to the citrates and phosphates which represent the negative charges. The amount of calcium that is available for the casein-calcium combination is determined by the balance between the calcium and magnesium group and the citrate and phosphate group of salts. An excess or deficiency of either group tends to unstabilize the casein.

3. In the absence of the proper balance of the salts in milk, heat coagulation difficulties can be guarded against by the addition of the proper amount of those salts in which the milk is deficient. In the great majority of cases of heat coagulation difficulties the trouble is due to an excess of calcium (deficiency of citrates and phosphates). Such milk is stabilized by the addition of a small amount of sodium citrate or di-sodium phosphate. If the low heat stability is due to a deficiency of calcium (excess of citrates and phosphates) the addition of a soluble calcium salt, such as calcium chloride, usually provides the desired improvement. Cases of calcium deficiency are rare.

4. Addition of salts for the correction of the salt balance are most effective when these salts, or a considerable portion thereof, are placed in the milk before condensing.

5. The effect of the salt balance on heat stability varies with many other factors, such as acid reaction, the presence of fermentation products other than acid, albumin and casein content, forewarming temperature, concentration of solids not fat, etc. In other words, as expressed by Benton and Albery, each lot of milk must be regarded as a separate colloidal system with its optimum combination of acid reaction and salt balance, for maximum heat stability.

6. Because of these facts, heat stability tests of the fresh milk, such as the alcohol test, the phosphate test, etc., do not always furnish a dependable index to the heat stability of the evaporated milk.

7. The above observations emphasize the value of the use of the pilot sterilizer for systematic control of the behavior of the evaporated milk in the sterilizer.

INFLUENCE OF FOREWARMING ON HEAT COAGULATION

The beneficial effect of high forewarming temperatures on the heat stability of evaporated milk has been known to the industry for over a quarter of a century and this knowledge has led those experienced in the art to the adoption of the practice of heating the milk in the forewarmer to near the boiling point, and holding it there for varying periods (frequently as long as 30 minutes) before drawing the milk into the vacuum pan.

It was, however, the researches of Rogers, Deysher and Evans,[33] Leighton and Deysher,[34] Sommer and Hart,[69] Deysher, Webb and Holm,[65] and Webb and Holm,[96, 87] that revealed experimentally the effect of different forewarming temperatures and periods on the stability of evaporated milk toward heat. The results of these investigations and the theories advanced regarding the reactions responsible for the effect of forewarming on heat stability are briefly summarized in the following paragraphs:

Summary of Effect of Forewarming on Heat Coagulation.—1. The stabilizing effect of forewarming appears to be lowest at 75° C. (167° F.). As the temperature of forewarming rises above this point, there is a gradual increase in heat stability. Forewarming temperatures above the boiling point yield maximum heat stability.

2. The increasing heat stabilizing effect of rising forewarming temperatures is accompanied by a lowering of the viscosity. At the higher forewarming temperatures the body of the finished product is too thin to satisfy market requirements.

3. The stabilizing effect of high forewarming temperatures does not materialize in milks of poor quality. When such

milks are forewarmed at temperatures above the boiling point heat stability diminishes. Forewarming at 95° C. (203° F.) for 5 to 15 minutes appears to produce optimum heat stability consistent with a satisfactory body under average conditions of milk.

4. The heat-stabilizing effect of forewarming varies with the concentration of solids-not-fat in the milk. Below 14 per cent solids-not-fat down to 10.5 per cent, forewarming either does not improve or decreases the stability, depending upon the individual milk used. Above 14 per cent solids-not-fat, forewarming improves the heat stability.

5. The levels of heat stability established for different forewarming temperatures are not materially changed in their relationship by different pressures of homogenization except in degree of stability.

6. The reactions involved in the heat stabilizing effect of forewarming are not as yet fully understood. Sommer and Hart[69] hold that this effect is due partly to the fact that the higher forewarming temperatures coagulate the albumin to a greater extent and partly to the precipitation of a larger amount of the calcium salts. The albumin coagulation minimizes the tendency of the formation of an albumin jell in the sterilizer. The precipitation of calcium salts improves the salt balance by precipitating the excess calcium as tri-calcium phosphate and by changing a part of the ineffective primary phosphates to effective secondary phosphates.

7. Webb and Holm[87] point out that forewarming appears to cause an irreversible change. They are of the opinion that this change is not confined solely to changes in the equilibria of the salt balance such as would result from the precipitation of calcium and the conversion of monophosphates to secondary phosphates, because they were unable to restore the stability by the addition of electrolytes, such as soluble calcium salts, or citrates, phosphates or carbonates, etc., in those cases where the stability had been reduced by the forewarming temperatures. They suggest that this irreversible change may be one of variations in the hydration of the calcium caseinate due to alteration in chemical composition.

8. It is probable that all three reactions enter into the heat

stability-improving effect of high forewarming temperatures, i. e., the casein coagulation point is raised by elimination of the unstabilizing excess calcium through precipitation of a part of the calcium and of changing primary phosphates to secondary phosphates; the calcium caseinate undergoes fractional hydration and swelling that diminishes the casein jell formation during sterilization; and a large portion of the albumin is coagulated and dispersed, thus diminishing the amount of soluble albumin available for jell formation in the sterilizer.

9. The heat-stabilizing possibilities of forewarming are further emphasized by the fact that the heat treatment made possible by the recirculation method of forewarming, as practised by some of the largest manufacturers of evaporated milk, has been found a dependable means of guarding against heat coagulation difficulties in the sterilizer without the use of any chemical stabilizers. For detailed description of this method see Chapter XII.

10. Available data on the composition of milk throughout the lactation period and on the same feed ration show, that the albumin and casein content and the calcium content are highest at the beginning and toward the end of the period of lactation, while the citric acid content tends to be lower toward the end of the milking period. These facts suggest that milk from cows that have recently freshened and milk from stripper cows, tend to have a relatively low heat coagulation point and are most likely to cause troublesome coagulation and sterilizing difficulties. This is in harmony with the general condensery experience. The use of relatively high forewarming temperatures and prolonged exposure, during those periods of the year, when the great majority of the cows either have recently freshened or are stripper cows, is therefore helpful in minimizing the troublesome coagulation. In most sections located in the northern hemisphere this condition applies to late fall, winter and early spring.

EFFECT OF CONCENTRATION ON HEAT COAGULATION OF EVAPORATED MILK

As the concentration of evaporated milk increases the heat coagulation point drops. This is shown by the work of Hunziker[94] in Table 16.

Table 16.—Showing the Increase of the Per Cent of Acid as the Concentration of the Evaporated Milk Increases and Its Effect on the Curdling of the Casein

Lot No.	Concentration	Per cent acid	Condition of casein
1	1.58:1	.34	Not precipitated
2	1.74:1	.34	Not precipitated
3	1.90:1	.40	Not precipitated
4	1.99:1	.43	Not precipitated
5	2.11:1	.48	Small lumps of curd
6	2.25:1	.54	Large lumps of curd

It has already been pointed out in previous paragraphs, that the concentration of acid, albumin and casein, respectively, lowers the coagulation point and that the salt balance very greatly affects it. In the case of increased acidity, due to concentration of the milk, the reaction may include also the change in phosphates suggested by Sommer and Hart. That is, with the more acid reaction in the concentrated milk, there is an appreciably smaller fraction of the secondary phosphate, which in turn has the effect of emphasizing the unfavorable influence of the usual excess of calcium in the milk.

Sommer and Hart.[84] and in a later report Sommer[92] found that the coagulation could be prevented by diluting coagulating samples with slightly over 10 per cent of distilled water. Their results further showed that dilution with water had a greater effect than diluting with the filtrate of the same milk sample, secured by filtration through a Pasteur-Chamberlain filter. These findings demonstrate conclusively that the concentration of the milk serum, as well as the concentration of the casein has an effect on heat coagulation.

Experiments of Holm, Deysher and Evans[57] show that an increase in concentration lowers the coagulating temperature, but they found that within the wide range of concentration they used—16 to 26 per cent solids not fat—the ratio of concentration to coagulation temperature was not constant. At higher concentrations there was a greater variation in the temperature of coagulation for every change of concentration than at the lower concentrations.

They also found that a change in concentration causes a somewhat greater change in temperature of coagulation in the case of evaporated skimmilk than for evaporated whole milk. A comparison between evaporated whole milk made from fresh milk of good quality and that made from fresh milk of inferior quality (the fresh milk was held at 18° C. for 24 hours) showed that the milk of inferior quality had a decidedly lower coagulation point, but the ratio of concentration to coagulating temperature was the same for both classes of milk. These investigators concluded that for every one per cent difference in concentration there was a difference of about 1.25° C. to 1.50° C. (2.25° F. to 2.7° F.) within a range of from 16 to 26 per cent solids not fat. Mojonnier and Troy[42] report that in normal evaporated milk, containing about 7.8 per cent fat and 25.5 per cent total solids, every 20 pounds of water added to or removed from 1,000 pounds of evaporated milk, raises or lowers the coagulating point 1° F., respectively.

Webb and Holm's[87] more recent study further shows that the concentration of solids not fat in evaporated milk materially influences the effect on heat stability of such factors as forewarming temperatures, acid reaction, and added electrolytes. Their results indicate that a concentration below 14% solids not fat causes high forewarming temperatures (203° F.) to lower the heat coagulation point, while with concentrations above 14% the same forewarming temperature increases heat stability.

In all comparisons of the influence of concentration on the effect of the acid reaction they found the heat stability of the concentrated milk lower than that of the fluid milk, and in the majority of cases an increase in acid reaction was accompanied by a corresponding decrease in heat stability in both the fluid and the concentrated milk. There were instances, however, where a slight increase in acidity caused an increase in the heat stability of the concentrated product, while it lowered the heat stability of the unconcentrated portion of the same milk.

The relation of concentration to heat stability assumes special significance in the manufacture of evaporated milk with a relatively high concentration, such as milk intended for export. In the United States the influence of the factor of concentration on heat stability was a determining factor in the establishment of the present federal standard for solids-not-fat and fat of evaporated milk, which is 17.7 per cent and 7.8 per cent, respectively.

EFFECT OF HOMOGENIZATION ON HEAT STABILITY OF EVAPORATED MILK

Homogenization tends to slightly lower the heat stability of evaporated milk. This tendency increases as the homogenizing pressure increases. The pressure and temperature at which evaporated milk is homogenized and their effect on heat stability are discussed in detail in Chapter XIII on "Homogenizing."

STANDARDIZATION OF PROPERTIES THAT INFLUENCE HEAT COAGULATION IN THE STERILIZER

In the foregoing discussion it was shown that there are numerous factors that influence the behavior of evaporated milk in the sterilizer. It was pointed out that some of these factors have to do with the process of manufacture and are therefore under control of the operator. Aside from the temperature and time of sterilization itself, the most important of these factors are temperature, time and method of forewarming, and degree of concentration.

Other factors have to do with the quality, composition and properties of the fresh milk. The most important of these are acidity, rennet-like products, albumin content and salt balance. These factors are largely beyond the control of the factory. Their effect on heat stability, however, can be modified by intelligent and careful adjustment of the processes that precede sterilization.

The advantages of standardizing the process of sterilization were pointed out in earlier paragraphs. It simplifies operation, makes for greater plant efficiency, and reduces the danger of excessive spoilage of the finished product. In order to make possible the use of a uniform, standard sterilizing process and at the same time insure against heat coagulation difficulties, it is necessary to standardize those properties of milk that largely control its behavior toward sterilizing heat. It is necessary to establish in the milk before sterilization the proper salt balance that will give the casein optimum stability under all reasonable conditions of the milk, and use the sterilizing temperatures that are known to insure complete sterilization of the evaporated milk.

The original method, as developed by Mojonnier Brothers Co., for the standardizing of the properties of milk that affect heat stability depends on sodium bicarbonate as the casein stabilizer. It was shown in previous paragraphs that sodium bicarbonate is capable of improving the salt balance, but that other sodium salts such as di-sodium phosphate and sodium citrate are even more dependable in their casein-stabilizing effect and are otherwise preferable because their use in no way damages the color and flavor of the finished product. The equipment required and the method of procedure are identical for these new stabilizers as for sodium bicarbonate. Hence the Mojonnier method as originally designed is here given, followed by brief directions for its adaptation to the use of di-sodium phosphate and sodium citrate.

CHAPTER XVI

METHOD OF EVAPORATED MILK CONTROL

The Mojonnier Method.—This method briefly consists of the following outstanding features:

1. The adoption of a standardized process of sterilization designed and adapted for evaporated milk of superior quality for processing. This process provides a very narrow range of variation of temperature and of time of exposure, in order to limit the personal factor with its inevitable uncertainties to the minimum.
2. A standard method of determining, by means of a pilot sterilizer, a viscosimeter and a color test, the proper viscosity and color that the evaporated milk should have when it comes from the sterilizer.
3. A standard method of determining the amount of bicarbonate of soda that must be added to any given batch of evaporated milk in case its properties are such that it is unsafe to subject it, without such treatment, to the temperature conditions that fall within the range of the standardized process of sterilization.

Equipment for Mojonnier Method.—The equipment designed for this method of evaporated milk control consists of the following apparatus:

1. One pilot sterilizer with motor, complete.
2. Two viscosimeters.
3. One venthole sample can filler.
4. Glassware for making up and measuring sodium bicarbonate solution.
5. One torsion balance.
6. Open-top cups and venthole tin cans.

Preparation of 10 per cent Sodium Bicarbonate Solution.—The bicarbonate of soda is used in this test in the form of a 10 per cent solution. This solution is prepared as follows:

1. Weigh empty bottle to .01 ounce.
2. Add 3 ounces bicarbonate to bottle.
3. Add 27 ounces warm water to bottle.

Shake thoroughly until the bicarbonate is all dissolved. Draw out as needed into dispensing bottle, filling the same not over half full. Keep remainder tightly corked in the stock bottle until needed. Should the bicarbonate crystallize out, prepare a new lot. The above solution contains exactly 10 per cent sodium bicarbonate.

Adding the Sodium Bicarbonate Solution to Sample Cans.—Arrange in a row five open-top cups marked—X-1-2-3-4 respectively. These cups are furnished with the Controller. Cup marked X is blank, to which no bicarbonate is added. To cup marked No. 1 add one charge of sodium bicarbonate from the dispensing burette. This is the amount contained between the upper two graduations on the burette. To cup marked No. 2 add two charges, to cup No. 3 add three charges, to cup No. 4 add four charges. Dispensing burette furnished with the controller indicates how the above quantities are to be added; the burette is graduated into four separate charges. The unit of one single charge contains the equivalent of one ounce of sodium bicarbonate, to one thousand pounds of evaporated milk. Each successive charge is a multiple of this unit. In dispensing the bicarbonate solution, it is best not to fill the bottle more than half full. When filling the burette, the solution should be allowed to flow into it slowly in order not to trap in the air. If air is trapped into the burette, it is difficult to remove it, and in such a case it is best to run out whatever solution may be in the burette and to put in a new supply.

Whenever the quality of the milk is very abnormal, it may be necessary to add more than the above indicated number of charges of bicarbonate solution to the sample cans. In such cases any multiples of the above number of charges may be added. The ratio of ounces of bicarbonate to one thousand pounds of milk will remain the same, being increased simply by the number of charges added to each sample can.

Preparation of the Five Sample Cans for the Sterilizer.—After the five open-top cups have been treated with bicarbonate as indicated in the preceding section, they are transferred to the Torsion Balance and exactly six ounces of milk is weighed into each cup. This can be done by taring the entire set of empty cups, and then weighing six ounces of evaporated milk into each separate cup.

One set of five empty cans is now marked in the same manner as the cups to which the bicarbonate solution was added, namely as follows: X = can containing no bicarbonate; 1 = can containing equivalent of one ounce bicarbonate per thousand pounds of evaporated milk; 2 = can containing equivalent of two ounces per one thousand pounds of evaporated milk; 3 = can containing equivalent of three ounces per one thousand pounds of evaporated milk, and 4 = can containing equivalent of four ounces per one thousand pounds of evaporated milk.

Next the contents of the five open-top cups are transferred to the five tin cans in the order above indicated. This is done by placing the cans in pairs, under the two-can venthole filler, furnished with the Controller, and the cups with the milk and bicarbonate marked corresponding to the empty cans, are now emptied into the filler. Care must be taken to keep the cans in the proper order.

After filling, the cans are "tipped," using preferably rosin solder. Should none of this solder be available, then great care must be exercised not to let any of the flux from the zinc chloride solder enter the can. Zinc chloride flux has a very bad effect upon the milk and will completely change the results.

Sterilizing the Five Sample Cans.—The five sample cans, prepared as above directed, are now ready for the sterilizer. Place these in the cage and fasten the lid securely, and also turn down the screws in order to hold all of the cans securely in place. Adjust the cage in the sterilizer by means of the thumb screw on the right hand side, in order to prevent end play. Close the sterilizer door securely so that no steam escapes during the sterilizing process.

Be sure to provide circulation of the steam through the vent on the pipe surrounding the thermometer. This little vent should be kept open during the entire sterilization operation. Fill the small pilot sterilizer with water to a point half way up on the gauge glass. Be sure to turn on the switch to start the motor in operation. Open the "steam start valve" and take five minutes to let the heat reach 190° F. or 3 on the sterilizer scale. Then let the heat come up gradually from 190 to 240° F. or from 3 to 8 on the thermometer, allowing one minute for each 5 degrees as indicated in the following table:

Table 17

Actual Temperature in Fahrenheit Degrees	Actual Reading upon Thermometer Scale	Time at which Mercury should be at any given point coming up
240°	8 points	20 minutes
230°	7 points	18 minutes
220°	6 points	16 minutes
210°	5 points	14 minutes
200°	4 points	12 minutes
190°	3 points	10 minutes

Where sterilizing is done with steam only, without using superheated water, it is recommended to allow twenty minutes for coming up. The above table is arranged upon this basis. The table, however, can be readily adapted to a system requiring fifteen minutes for coming up, by taking five minutes to come up to the point marked 10 upon the table, or to 190° F.

It is also recommended that in the pilot sterilizer, the samples be cooked to 243° F. and that the "jump" from 230° F. to 243° F. be made in two minutes. It is very important to know the exact second when the mercury column reaches 243° F. The milk should be held at this temperature for fifteen minutes to the exact second.

Cooling the Five Sample Cans.—The instant the clock shows that the samples have been sterilized as indicated above, both discharge valve and cold water valve should be opened simultaneously. It is best to cool the five samples to about 75° F. This should take not to exceed five minutes, depending upon the temperature of the water available. This is something each operator must judge for himself.

Examination of Sample Cans.—As soon as the sample cans are cooled in the sterilizer, as indicated above, they are taken out, opened and their contents examined for viscosity and smoothness. The use of the viscosimeter assists in the accurate determination of viscosity.

Importance of Proper Viscosity.--The viscosity of evaporated milk determines the body and permanency of the emulsion of the fat and other solids and liquid constituents of the product and it further determines the extent to which the evaporated milk may be expected to withstand the sterilizing heat without danger of curdling in a manner that would render the product unmarketable.

The purpose of the viscosity test on sample cans having passed through the pilot sterilizer or controller is, to determine whether the evaporated milk of the entire batch, without treatment, will safely pass through the adopted, standard sterilizing process, or to what extent this process must be modified, or to what extent the product, before sterilization must be treated with bicarbonate of soda or other sodium salts, as discussed later in this chapter, to secure a good body, and at the same time insure freedom from the formation of a permanent curd when applying the standard sterilizing process.

A certain degree of vicosity in evaporated milk is desirable and necessary in order to give the product a good body and to prevent the separation of the butter fat. But, as the viscosity increases a point is reached beyond which it is not safe to go, because of the danger of the formation of a permanent curd that renders the product unmarketable.

Increased viscosity is due to a change in the physical properties of the protein constituents of evaporated milk resulting from the action of heat. This change is now understood to be due largely to an unbalancing of the calcium-casein equilibrium and to the coagulation of the milk albumin, caused by the high temperature of sterilization. The earlier stages of these changes are desirable, because they result in a product of good body and of increased stability of emulsion. An excessive continuation of these changes precipitates the proteins in the form of visible particles of curd which, if permanent, spoil the product for the market.

Factors Which Influence the Viscosity, and Their Relation to the Sterilizing Process.—The extent to which heat increases the viscosity of evaporated milk is dependent on the many and varying conditions that influence its heat coagulation point. The resistance of the proteins to heat, as affected by these several conditions and factors, can be modified and largely controlled if necessary, by the treatment of milk that has an abnormally low resistance to heat, with definite, small quantities of bicarbonate of soda, di-sodium phosphate or sodium citrate.

The viscosity test therefore furnishes a measure of the resistance of any given batch of evaporated milk toward sterilizing heat. But in order to enable the operator to correctly interpret the results of this test and to correctly govern his method of handling the evaporated milk according to these findings, he should have a clear understanding of the correlation of the several factors that influence this resistance to heat and that affect the viscosity.

With reference to the direction (increase or decrease of viscosity) in which these several factors influence the viscosity and the tendency to curdle the evaporated milk, the following general facts should be known:

Factors that **Increase** the viscosity and the tendency of the milk to curdle.

1. High per cent acid in milk
2. Presence of bacteria producing rennet-like substances
3. High albumin content
4. Excess of calcium over citrates and phosphates
5. Excess of citrates and phosphates over calcium
6. Low forewarming temperature
7. High concentration of evaporated milk
8. High pressure in homogenizer
9. High sterilizing temperature
10. Long exposure to sterilizing temperature.

Factors that **Decrease** the viscosity and the tendency of the milk to curdle.

1. Low acid in milk
2. Absence of bacteria producing rennet-like substances
3. Normal albumin content
4. Optimum calcium-casein balance
5. High forewarming temperature
6. Holding at forewarming temperature
7. Low concentration of evaporated milk
8. Low pressure in homogenizer
9. Extraneous water in evaporated milk
10. Low sterilizing temperature
11. Short sterilizing process
12. Addition of bicarbonate of soda, di-sodium phosphate or sodium citrate.

On the basis of the Mojonnier-Doolittle viscosimeter test and applying to evaporated milk standardized to 7.8% fat and 25.5% total solids, Mojonnier and Troy[42] show that a 40 degree retardation corresponds to:

1. One degree F. above 240° F. when holding for 15 minutes.
2. One minute of holding at 240° F. longer than 15 minutes.
3. Two degrees F. in hot well less than 212° F.
4. Twenty pounds of extraneous water added per 1,000 pounds of evaporated milk.
5. One ounce of solid sodium bicarbonate per 1,000 pounds of evaporated milk.

When using the above correlation of factors as a guide, it should be borne in mind that, with evaporated milk of a higher degree of concentration the influence of these several factors on the retardation or viscosity is altered and intensified.

The Correct Viscosity for Evaporated Milk.—The experimental study of the viscosity of evaporated milk by Mojonnier and Troy[42] has further demonstrated that a considerable portion of the viscosity, as determined immediately after the evaporated milk comes from the sterilizer, is lost during the handling to which the product is subjected from the time it leaves the sterilizer and until it is ready to leave the shipping department, and again in transport until it reaches the consumer. Also, the extent of this loss of viscosity is governed somewhat by the temperature of the milk while it is so handled; the higher the temperature the greater the sacrifice in viscosity.

Accordingly it has been found that for domestic trade a retardation or viscosity of 150 degrees is the correct viscosity for evaporated milk just as it comes from the sterilizer. For export purposes the viscosity should be higher, around 200 degrees.

A 150 degrees viscosity of evaporated milk immediately after sterilization is equivalent to a viscosity of from about 80 degrees to 100 degrees by the time the milk is ready to leave the shipping department, and this represents about the correct viscosity for the summer months. For the winter months the viscosity should not exceed about 80 degrees retardation. Excessive viscosity invites the "feathering" or curdling of the evaporated milk when used in hot coffee or when diluted with hot water.

Adding Sodium Bicarbonate to Batch of Evaporated Milk.—As soon as the controller and viscosimeter tests are completed, the batch of evaporated milk is ready to be filled into the tin cans. In case it is necessary to add sodium bicarbonate, the following procedure is recommended:

For convenience sake we will assume that can No. 2 in the test showed the correct viscosity, as represented by a retardation of 150 degrees. To this can was added sodium bicarbonate on the basis of two ounces per 1,000 pounds of evaporated milk. The entire batch of milk contains 24,000 pounds evaporated milk, hence $\frac{24{,}000 \times 2}{1{,}000} = 48$ ounces of solid sodium bicarbonate are carefully weighed out. This amount of bicarbonate is conveniently placed into a 10-gallon milk can, a small amount of water is added and preferably also a small amount of evaporated milk. This mixture is then heated to a vigorous boil, which can easily be done by means of the steam hose. The boiling should be continued until the greater part of the gas generated has been expelled.

The hot mixture is now added to the entire batch of evaporated milk in the holding tank. It should be added slowly and the evaporated milk should be kept thoroughly agitated, not only while the bicarbonate is added but for from 10 to 20 minutes after its addition.

Irregularities in the Reaction and Results of Sodium Bicarbonate.—Generally speaking the Mojonnier formula above given for the use of bicarbonate of soda yields reliable results. Sommer and Hart[60] showed that there are occasionally conditions, however, when the evaporated milk fails to react normally with this ingredient and may yield results exactly opposite those anticipated. Instead of reducing the viscosity and increasing the heat coagulation temperature, it increases the viscosity and lowers the heat coagulation point.

It is within the range of possibility that such a condition may be caused by a shortage of calcium in the salt balance of the milk, in which case the addition of sodium salts, such as sodium bicarbonate would intensify the derangement of the calcium-casein balance. Such occurrences do occasionally happen in the case of milk from individual cows, but with mixed herd milk and especially with mixed milk from many herds, as is represented by any batch of commercial evaporated milk, they are exceedingly rare. Sommer[92] reports that in no case of condensery difficulties was the trouble due to a shortage of calcium in the milk. In all cases of sterilizing difficulties that were due to a faulty salt balance the trouble was caused by an excess of calcium and could be avoided by the addition of sodium salts.

The most likely instances of evaporated milk failing to respond to treatment with sodium bicarbonate are those in which the calcium-casein molecule has undergone abnormal chemical changes resulting from faulty handling of one or more steps in the process of manufacture, such as improper methods of forewarming, excessive dilution with water, leakage of calcium chloride brine, using excessive amounts of sodium bicarbonate, etc.

THE USE OF SODIUM CITRATE AND AND DI-SODIUM PHOSPHATE

The relative merits of sodium citrate, di-sodium phosphate and sodium bicarbonate as a means to correct the salt balance and raise the heat coagulation point in evaporated milk are discussed in Chapter XV, under the heading, "Effect of Mineral Salts on the Heat Coagulation Point."

Under average normal conditions the corrective effect of the three sodium salts on the heat coagulation point is similar. Their addition improves the salt balance in milk that contains more calcium than will produce the optimum calcium-casein balance and maximum casein stability.

Advantages of Citrates and Phosphates.—The results with citrates and phosphates, however, are somewhat more regular and more dependable than with sodium bicarbonate. This is attributed to the fact that sodium bicarbonate has a double action. Similar to the citrates and phosphates, it balances excess calcium. But in addition to this it changes the acid reaction and when used in large amounts it may magnify the excess calcium by combining with the casein and replacing the calcium in the calcium-casein combination. When this occurs, the result is the opposite of what is desired. The calcium-casein equilibrium is further impaired and the heat coagulation point is lowered instead of raised. The citrates and phosphates, on the other hand, act in one direction only, they balance the excess of calcium. This fact renders their effect more positive and dependable.

Again, the bicarbonate tends to intensify the darkening of the color. It also is prone to impair the flavor of evaporated milk. These disadvantages become more noticeable with an increase in the amounts of bicarbonate used. The natural, bright, creamy color changes to a grayish-brown, muddy shade and the flavor gives the impression of soapiness. Furthermore, the bicarbonate tends to cause the cans to bulge more at the ends on account of the release of carbon dioxide gas under sterilizing heat. This subjects the cans to an increased strain and may result in a high percentage of leakers. It also may cause the cans to reach the market with bulged ends, giving the trade and consumer the impression that the contents of the cans have spoiled. The use of sodium citrate or di-sodium phosphate is not accompanied by these damages.

How to Use Sodium Citrate and Di-Sodium Phosphate.—The amount of sodium citrate or di-sodium phosphate to add to any given batch of evaporated milk is determined by trial in a manner similar to that used where sodium bicarbonate is the casein stabilizer. For this purpose a number of six ounce evaporated milk cans (8 to 10 tins) are used and the test is made in the pilot sterilizer. The samples are prepared by adding varying amounts of either sodium citrate or di-sodium phosphate to the individual sample tins containing the unsterilized evaporated milk to be tested. Sommer and Hart,[69] on the basis of their results both in laboratory experiments and in evaporated milk factories, found that the range usually covered in such a series is the equivalent of from 2 to 10 ounces of dry citrate or phosphate per 1,000 pounds of evaporated milk. They further suggest that, while in exceptional cases an addition of 16 to 20 ounces per 1,000 pounds of evaporated milk may be required, in most cases of unbalanced salts in evaporated milk, the range of 2 to 10 ounces will cover the amount required to restore the balance and to insure a satisfactory sterilizing process. They recommend the following procedure:

Preparation of Solution.—Add the citrate or phosphate in the form of a solution. The strength of the solution should be such, that one-tenth of a cubic centimeter of the solution is equivalent to the addition of 1 ounce of the dry salt per 1,000 pounds of evaporated milk. This requires a solution containing 10.63 grams of the citrate or phosphate dissolved in enough water to make up 100 cc. of solution. Because of the lower cost of di-sodium phosphate, this discussion will confine itself to the use of phosphate only.

Preparation of Sample Tins.—Use a 1 cc. pipette graduated to one-tenth cc. The tip of this pipette should be drawn to a point sufficiently small so that it may readily be inserted into the venthole of the usual evaporated milk can. In order to prevent loss of solution due to some of it being blown out with the air that escapes past the tip of the pipette, it is best to add the solution to the cans before they are filled with the milk.

Compensating for Effect of Dilution of Sample.—The addition of the salt solution dilutes the evaporated milk. This factor alone has a slight influence on the heat coagulation point of the milk. In order to eliminate this factor it is advisable to equalize the dilution in all samples of a given series. The exact procedure is shown in Table 18.

Table 18.—Showing Method of Preparing Samples.

6 ounces of unsterilized evaporated milk, plus:	cc. of 10.63% di-sodium phosphate solution	0.0	0.0	0.2	0.4	0.6	0.8	1.0
	cc. of distilled water	0.0	1.0	0.8	0.6	0.4	0.2	0.0
Rate of addition required, and expressed as ounces of dry-di-sodium phosphate per 1,000 pounds of unsterilized evaporated milk.......		0	0	2	4	6	8	10

In the above table the first sample represents the evaporated milk without any addition. The second sample, contains no phosphate but represents the milk in diluted form, the rate of dilution being the same as that of all the other samples. The remaining samples represent additions to phosphate in varying amounts, but with the dilution in all cases equal to the second sample. By this procedure, it is possible to determine to what extent the improvement in the coagulation is attributable to the dilution and to the phosphate, respectively.

Making the Test.—The sample tins thus prepared are placed in the pilot sterilizer where they are subjected to the full temperature and time exposure that is known to yield safe sterilization from the standpoint of germ-killing efficiency, i. e., a sterilizing process similar to the factory process is used, detailed instructions for which have been discussed in preceding paragraphs. After sterilizing and cooling the samples are examined for coagulation, viscosity and color and the sample showing the desired properties is noted, making due allowance for the slight effect of the dilution. By consulting the record of di-sodium phosphate added, the operator knows the amount of added phosphate solution this tin contains, and by multiplying the cc. of solution by 10, he may then determine the ounces of dry di-sodium phosphate per 1,000 pounds of evaporated milk to add to the entire batch.

Addition of Di-Sodium Phosphate to the Batch of Evaporated Milk.—For every one-tenth cubic centimeter of phosphate solution contained in the sample can the contents of which responded best to the sterilizing process in the pilot sterilizer, one ounce of dry di-sodium phosphate per 1,000 pounds of evaporated milk must be added to the commercial batch.

It is very important that the phosphate be thoroughly mixed in and diffused completely throughout the entire batch or tank full of evaporated milk. To facilitate this it is desirable to dissolve the dry phosphate in a small amount of water, before adding it to the milk and after addition, to agitate the evaporated milk in the storage tank for several hours.

Since the casein-stabilizing effect of the sodium salt is most pronounced when the added phosphate is in the milk during the forewarming and condensing process, it has been found advantageous to add at least a portion of the required amount to the milk at the forewarmer and then complete the correction by adding the remainder to the evaporated milk in the storage tank. In order to do this, the operator may use the results of the previous day's work as a basis upon which to determine the approximate amount of phosphate that may safely be added. While the salt balance may differ somewhat in the milk of individual batches, these differences from batch to batch and between successive days' runs are generally not sufficient to require material changes in the amount of phosphate needed. Where all the batches of the same day's make are mixed, these variations are still less pronounced. Large variations from day to day are the exception and are usually due to accidental causes. The major variations in salt balance are generally of seasonal occurrence, due to change in period of lactation and feed. For further details see Chapter XV on "Factors that Influence the Heat Coagulation of Milk."

The Ethics of Adding Mineral Salts to Evaporated Milk.—In principle, the addition of extraneous substances to a food product such as evaporated milk, is not desirable—in fact it is contrary to the letter of our pure food laws and regulations. The directions in the preceding paragraphs should not be interpreted to mean that this volume advocates the indiscriminate use of mineral salts in the manufacture of evaporated milk, in an effort to convert a product made from insanitary, partly fermented or unwholesome raw material into a marketable commodity.

However, extensive and careful scientific researches and universal experience in commercial manufacture have conclusively demonstrated that the addition of small amounts of such mineral salts as sodium bicarbonate, sodium citrate and di-sodium phosphate do in no way impair the wholesomeness and food value of evaporated milk. They have further shown that the intelligent and proper use of these salts, where necessary, has proven a decided benefit to the industry, reducing the occurrence of unmarketable, though otherwise perfectly good batches of evaporated milk, to a negligible minimum, and thereby eliminating avoidable and unnecessary but costly economic losses.

The practice of facilitating the sterilizing process by the use of bicarbonate of soda is of long standing and in more recent years, as the result of scientific investigations at our state experiment stations, the use of sodium citrate and di-sodium phosphate has found wide application for the same purpose. This practice has become fairly well established, accepted by the industry and approved by scientific authorities. Its abuse, however, cannot be too strongly condemned and its promiscuous use in the absence of a systematic, scientifically controlled, correct method, as outlined in this volume, is prone to invite misuse.

The more recent experimental results dealing with the factors that influence heat stability emphasizes the possibilities of control of heat stability by means of proper adjustment of the heat treatment of the milk prior to sterilization. These results are further supported by experience with improved methods used in commercial manufacture. The present trend, in fact, is to control heat coagulation of the evaporated milk in the sterilizer by the proper adjustment of the temperature and time of forewarming, and thus make unnecessary the addition of chemical salts to the milk.

CHAPTER XVII

STERILIZING EVAPORATED MILK BY THE CONTINUOUS PROCESS

The discussion of sterilizers and processes of sterilization in the previous chapters referred to batch sterilizers of various designs and capacities. Indeed, up to about a decade ago sterilization by batches was the only system used for sterilizing evaporated milk. Aside from the limited capacity of the batch sterilizer and the time and labor-consuming features of this system, the difficulty of uniformity of heat distribution and control is one of the ever-recurring weaknesses of batch sterilizers.

These drawbacks are successfully eliminated by the advent and perfection of the continuous sterilizer, invented, designed and manufactured by the Anderson-Barngrover Manufacturing Company of San José, California. This machine was originally designed for the processing of fruits and vegetables and its adaptation to the sterilization of evaporated milk is of more recent date.

One of the important mechanical problems in the development and perfection of the continuous sterilizer was that of protecting the can against too great a strain due to pressure differences between the interior and exterior of the can. This was successfully solved by so designing the sterilizer as to preheat the cans gradually to a temperature a few degrees below the boiling point, before they enter the sterilizer proper, to release the sterilized cans into the cooler and to cool them under air pressure, and to provide the intake and discharge of the cooker and the cooler with a type of rotary, pressure-tight valves that insure satisfactory continuous operation without loss of pressure.

These efforts also gave birth to the invention of ingenious devices for the detection and elimination of defective cans and light weight cans. These detector devices have been perfected to the point where they now constitute an integral part of the continuous sterilizer.

Description of the Continuous Sterilizer.—The evaporated milk continuous sterilizer furnished by the Anderson-Barngrover Manufacturing Company consists of four principal units: the Preheater, the Variable-Inlet Preheater, the Sterilizer or Cooker, and the Cooler. Built on and operating as an integral part of the two preheaters and the cooler are three ingenious devices that separate the leaky cans and lightweight cans from the cans that are perfectly sealed and that are full weight.

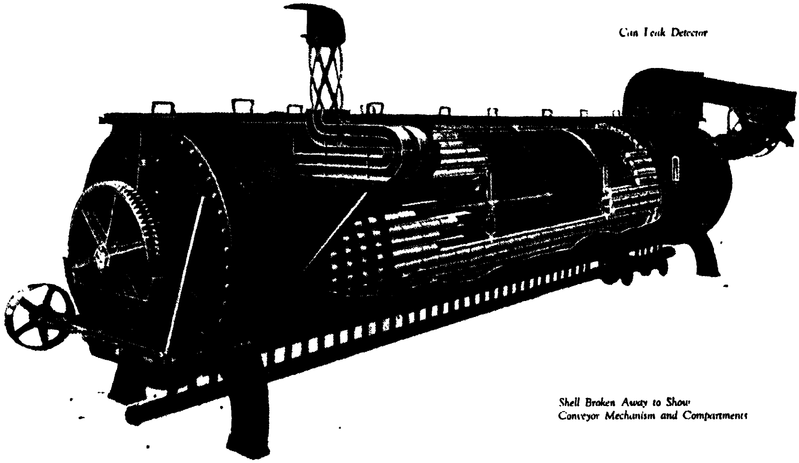
Can Leak Detector
Shell Broken Away to Show Conveyor Mechanism and Compartments

Fig. 84. Continuous sterilizer showing reel arrangement
Courtesy of Anderson-Barngrover Mfg. Co.

Each of the four main units consists of a horizontal cylindrical steel drum, equipped in its interior with a revolving reel that causes the cans to travel in a spiral track from intake to discharge. By this arrangement of conveying the cans through the four units, each can is contained in an individual pocket or compartment, which keeps it separate from the other cans in the unit. The time required for the can to pass through the unit is, therefore, the same regardless of whether the machine is operating at full capacity or whether only a few cans are being processed. This time may be varied at will by changing the speed of the machine which is usually equipped with a Reeves Variable-Speed Drive.

The Preheater.—The preheater is the first unit which the can enters. Its purpose is to preheat the milk, raising its temperature from the filling temperature (40 to 65° F.) by a gradual rise to from 180 to 205° F. at the discharge. This rate of rise and this discharge temperature can be altered at will, and once set is held constant by automatic temperature controls. The reel in this unit is divided into eight compartments which are separated from each other by circular baffle plates that rotate with the reel. In each compartment a different temperature may be maintained, thus permitting a gradual rise in temperature of the milk in the can as the can travels through the eight compartments.

The heating medium used in the preheater is hot water. The drum is filled with water to the bottom of the intake chute, or about three-quarters full. The water is heated with steam from the header that extends along the outside of the drum and connects with each compartment through a lateral. Each lateral steam line carries a stop cock so that steam may be admitted to any one or all of the compartments as required. This preheater unit is operated under atmospheric pressure and the correct water level is controlled by means of an overflow connection.

When the cans enter the preheater they have atmospheric pressure on the inside and a temperature of 40 to 65° F. As the temperature rises, the milk and air in the cans expand. The pressure thus formed causes the ends of the cans to bulge. In the case of hermetically sealed cans (cans without leaks) this bulging increases the length of the can one-quarter inch at 200° F. Cans with leaks do not bulge, their length remains the same as it was at the intake, because the pressure resulting from the expansion of their contents is dissipated through the leak.

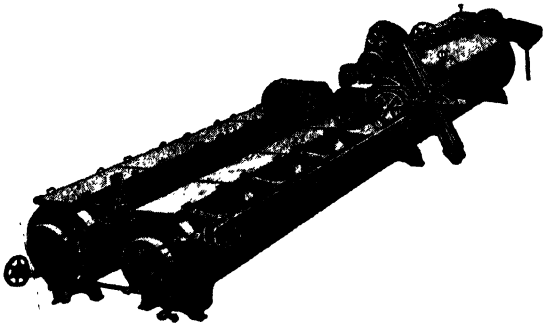

Fig. 85. Continuous sterilizer unit consisting of preheater, variable-speed pre-heater, sterilizer and cooler

Courtesy of Anderson-Barngrover Mfg. Co.

This fact permits the leakers to be separated from the air-tight cans by passing them through a Leak Detector as they emerge from the preheater.

The Leak Detector.—This ingenious device has two revolving discs, far enough apart so that the can with flat ends can roll between them. But the discs are not sufficiently far apart to permit a can with bulged ends to pass. The bulged cans are picked up by the discs, carried over the top and "stripped out" on the opposite side by means of an extension of the bottom of the can track that carries the cans to the next unit. In this manner the good cans (the cans with bulged ends) pass on to the variable inlet preheater, while the leakers (the cans with flat ends) escape on a lower track where they are trayed, ready to be "cut back."

The Variable-Inlet Preheater.—In the continuous sterilizer, as originally designed, the cans passed from the preheater direct to the sterilizer or pressure cooker, but later it was found that a longer exposure to a temperature just below the boiling point was beneficial, tending to increase the viscosity and assisting in the control of heat coagulation. The proper time of this exposure varies with the character of the milk as determined chiefly by season of year and concentration of milk solids. See also Chapter XV on "Factors Influencing the Heat Coagulation of Evaporated Milk." In order to take care of these variations in time of exposure to preheating temperatures, the variable-inlet preheater is equipped with four separate points of intake, each one of which may be used.

Aside from having four inlets. this machine differs from the first preheater in that it has no baffle plates in the reel. The temperature is, therefore, substantially the same over the entire length of the drum. It is equipped with the same type of leak detector as the first preheater, and any can with defective seal, or which opens up a seam because of the pressure difference between inside and outside of a can while passing through this unit will be rejected as the cans pass through the leak detector on their way to the sterilizer or cooker.

The Sterilizer or Cooker.—The sterilizer or cooker and the cooler are separate units, but are connected by a transfer valve that transfers the cans from the cooker to the cooler under pressure, and as the unison of timing of the reels of the two units and the transfer valve are essential, the gearing of each unit is connected with the same drive shaft.

The sterilizing temperature is from 240 to 245° F. and the steam pressure from 11 to 15 pounds. The cans enter the sterilizer against this pressure by means of a rotary intake valve that is so designed that very little pressure, if any, is lost. The steam enters the sterilizer through laterals from the steam header. These laterals connect with a square log or trough welded to the bottom of the drum, that forms a settling chamber or catch basin for the accumulation of rust and other foreign matter. As originally designed, the cans rolled on the reel or spiral as they passed the lower half of the shell. Experience showed this arrangement to cause too much agitation and low viscosity of the milk. In order to correct this, the reel design of the sterilizer was changed, being constructed of specially shaped I-beams that carry the can without rolling or rotating on its own axis. This is one of the important recent improvements in the present sterilizer. The can is now permitted to turn only over a distance of the first 30 inches upon entering the sterilizer. From there on, the only movement of which the can partakes is the sliding lengthwise and the single turn it makes for each revolution of the reel.

At the discharge end of the sterilizer the cans are pushed up and out of the reel into the pockets of the valve rotor by a star-shaped internal pinion that is driven by the reel which here acts as driving gear. The flights on the reel match the teeth on an internal gear and the star points correspond to the teeth of an internal pinion. The cans lie between the flights of the reel and as the points of the star engage these flights, the star points displace the can, raising it into the valve pockets which synchronize with the reel flights. The valve carries the can across to the port on the opposite side and drops it by gravity into the flights of the cooler reel whose rate of travel also synchronizes with the speed of the transfer valve.

The Cooler.—This is the fourth and final unit of the line that comprises the continuous sterilizer. During the cooking or sterilizing process the milk has reached a temperature of 240 to 245° F., creating a pressure in the can of approximately 33 pounds. If this can were now brought into atmospheric pressure, its internal pressure would so magnify the bulge as to greatly weaken and distort the can permanently and there would be a tendency of the seams of many of the cans to burst. In order to avoid this danger, cooling must be done under pressure.

The cooling is done with cold water, the cooler being filled with the water nearly up to the intake valve. Air is admitted under pressure above the water level and the pressure is maintained in the cooler by means of an automatic controller in the air line. The water level is maintained by an automatic control in the water line. The temperature is controlled either by a hand operated valve or by a temperature controller in the overflow line. The cans are cooled to approximately 70° F., after which they are discharged through a pressure-tight rotary valve by a star-shaped pinion in the same manner as described in connection with the discharge of the sterilizer.

Positive Discharge of Cooler.—As the cans leave the pockets of the cooler discharge valve, they drop by gravity into the "can run" which carries them to the labeler. If this can run were accidentally closed so that the cans would back up to the discharge valve, the next can due to fall out of the valve pocket would be held in and the can would "repeat," i. e., it would go around in the valve a second time. This would not leave an empty pocket for the next can coming off the reel and on this second turn of the valve two cans would be forced into the same valve pocket, causing a "jam." In order to avoid such accidents, a positive discharge disc has been installed in the run next to the valve. This is a disc, gear-driven and timed with the valve, that contains pockets to hold the cans. The cans fall from the valve pockets into the positive discharge disc pockets and in case the runway is blocked, the cans are forced out of the disc pockets by a "stripper" and fall on the floor until the runway is cleared.

Cooler Leak Detector.—As previously explained, when the cans, with their high internal pressure resulting from the expansion of milk and air in the sterilizer, enter the cooler, the can ends are bulged. Should a leak in the can develop during the time of high internal pressure, the pressure in the can is not reduced below the air pressure maintained in the cooler, because the compressed air in the cooler filters through the leak and maintains the internal pressure of the can corresponding to the air pressure in the cooler. This is the case, notwithstanding the automatic contraction of the milk and air in the can due to cooling. This equalization of internal pressure of the can and air pressure in the cooler in the case of leaky cans is sufficient to keep the ends of these cans bulged when the cooler discharges them into the can runs. On the other hand, a normal can that is hermetically sealed will have practically no internal pressure and its ends will be pressed into their original flat shape by the air pressure in the cooler. This difference between cans with proper and with defective seal permits of the use of a third leak detector which is placed in the can run close to the positive discharge disc. And here, all such leaky cans are "thrown out" by passing them between two revolving discs. In the case of this third leak detector, however, the process of leaker elimination is the reverse of that described for the preheater leak detectors; for here the bulged cans are the leakers and the cans with flat ends are those with their seals intact.

The Light-Weight Detector.—This accessory of the Anderson-Barngrover continuous sterilizer has for its purpose the elimination of all underweight cans. It was observed by the inventors from a close and careful check of the cans passing through the sterilizer, that cans that are a trifle light or a little weak during the process, either in the batch or continuous system, may spring a leak and a small quantity of the evaporated milk escapes. These cans may seal over again, but are short weight and usually they result in bloats.

In order, therefore, to protect the canner against this danger of light-weight cans and bloats reaching the market, a detector

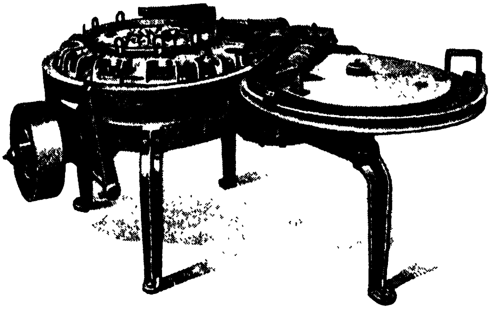

Fig. 86. Light-weight can detector
Courtesy of Anderson-Barngrover Mfg. Co.

was designed and perfected which operates at the rate of 160 cans per minute and which culls out all underweight cans. This detector is shown in the accompanying illustration.

Outstanding Merits of the Continuous Sterilizer.—The continuous sterilizer for evaporated milk as designed, developed and perfected by Anderson-Barngrover Manufacturing Company has long passed the experimental stage. It has become an established fact. Statistics reveal that today approximately 55 per cent of the annual output of the one and one-half billion pounds of evaporated milk manufactured in the United States is processed in this machine.

The continuous sterilizer changes the system of sterilizing from that in which the batch is the unit to one in which the individual can is the unit. It takes advantage of the natural contour of the can, which is cylindrical, making the can do the work, in the place of human muscle. It does away with the crude, laborious and time-consuming work of handling heavy trays, of loading and unloading trucks and batch sterilizers and of stacking, taking down for inspection, and restacking the heavy trays.

The operation of the entire machine is automatic and continuous. Temperatures and pressures are accurately controlled by automatic devices. A "coming up" and preheating system is provided that permits of suitable adjustment of viscosity and heat coagulation of the finished product. It insures accurate and dependable detection and elimination of defective cans. It reduces the risk of subsequent spoils to a negligible minimum and thus makes commercially practicable the conveyance of the cans from the sterilizer direct to the labeler and caser, and ready for immediate shipment. It eliminates the incubation process with its loss of time, damage to the product, need of large floor space, inaccurate and expensive hand inspection and laborious handling.

Careful timing of the journey of the can, from the time the empty can is unloaded at the factory, to the filler and sealer, through the continuous sterlizer, labeler, caser and case sealer, until it is loaded into the car ready for immediate shipment to the market, showed that the time required for this entire cycle of operation is reduced to the short span of approximately 50 minutes.

CHAPTER XVIII

PLAIN CONDENSED MILK, SEMI-SOLID BUTTERMILK AND CONCENTRATED SOUR SKIMMILK

PLAIN CONDENSED MILK

Definition.—This is an unsweetened condensed milk. It is made from whole milk, partly skimmed milk, or from all skimmilk. Its ratio of fat to solids and its percentage composition are adjusted to suit the particular requirements of the purchaser. It is condensed to concentrations ranging from 2½:1 to 4:1. Much of this product is superheated. The bulk of the plain condensed milk is packed in 10-gallon cans for ice cream factories. A limited amount is sold in milk bottles direct to the consumer. This product is not sterile, nor is it preserved by cane sugar. Its keeping quality is similar to that of a high quality of efficiently pasteurized milk.

Quality of Fluid Milk.—A good quality of plain condensed milk with a nice smooth body requires the use of fresh, sweet milk or skimmilk. Milk or skimmilk that has undergone considerable acid development, or that has been allowed to age without increase in acidity, is prone to cause the appearance of objectionable flakes and lumps in the finished product. This danger is intensified where superheating is practiced.

The principles that underlie the control of the heat coagulation point of evaporated milk enter into the successful manufacture of plain condensed milk also, though the relationship differs because this product is not exposed to the rigors of high sterilizing temperatures. The problem here is not one of raising the heat coagulation point, but to preserve the low heat coagulation point in a highly concentrated product without the formation of lumps of curd; it is to obtain maximum viscosity in a perfectly smooth product. This requires milk or skimmilk that is fresh, and sweet.

Forewarming.—The preheating or forewarming is carried out by the use of the same equipment and method as in the case of evaporated milk, but the milk is not heated to as high a temperature.

It was shown under evaporated milk, Chapter XII, that forewarming at high temperatures (190 to 210° F.) lowers the viscosity and raises the heat coagulation point, while low forewarming temperatures increase the viscosity and lower the heat coagulation temperature. In plain condensed milk a high final viscosity is desired, hence lower forewarming temperatures are preferable.

The best temperature at which to forewarm this milk must depend on whether the batch is to be "finished" with or without superheating. If no superheating is contemplated forewarm at 170° F. or slightly above. If the process includes superheating forewarm within a range of 140 to 160° F. At higher forewarming temperatures the milk does not respond so satisfactorily to subsequent superheating.

Condensing.—The milk is condensed in the vacuum pan in a manner similar to that described for sweetened condensed milk and evaporated milk, except that evaporation is carried to a higher point of concentration. See also "Condensing Milk by Continuous Process," described later in this chapter. As this product is not subsequently sterilized it is of special importance to thoroughly wash and steam the vacuum pan before use. See "Starting the Pan," Chapter VIII.

Ratio of Concentration.—Plain condensed skimmilk is usually condensed at the ratio of 3:1 to 4:1. At a concentration of 3:1 (total solids approximately 27%) the Baumé reading at 120° F. is about 12 to 13°Bé. At a concentration of 4:1 (total solids approximately 36%) the Baumé reading at 120° F. is about 16½ to 17½ Bé.

For plain condensed whole milk the Baumé readings for different concentrations at 120° F. are approximately as follows, the exact readings varying somewhat according to the ratio of fat to solids not fat:

Concentration	**Baumé at 120° F.**
2.5 to 1	7.5 to 9°
3 to 1	10.5 to 12°

Striking.—This is usually done by the use of the Baumé hydrometer in a similar manner as indicated for evaporated milk, Chapter XII, except that for plain condensed skimmilk a hydrometer scale extending to at least 18° Bé is needed. In the case of plain condensed milk that is to be superheated it is advisable to condense slightly above the desired concentration in order to compensate for the slight dilution of the milk during superheating. Experience has shown that about 2.0° Bé above the desired reading is sufficient.

Unless the process includes superheating, the batch is now ready to be dropped from the pan and cooled.

Superheating.—The superheating is accomplished by blowing "live steam" into the milk in the pan. The pan is equipped for this purpose with a direct steam line without pressure reducing valve and terminating in the pan near the bottom in a steam distributing device.

The usual pan-operating temperature of 135 to 140° F. is maintained up to the beginning of the superheating. The steam to jacket and coils is then shut off. The water supply to the condenser is closed, the vacuum pump is stopped and the valve in the superheating steam line is opened wide, permitting the steam to pass into and through the milk under full pressure. This immediately lowers the vacuum and raises the temperature in the pan. The superheating is continued until the temperature has risen to 180 to 200° F. and the vacuum has dropped to about 13 to 7 inches. The superheating temperature is maintained until the milk has become sufficiently thick, or in the language of the processor, has developed the "proper liver." This is determined by the appearance and behavior of the milk in the pan as seen through the spy glass, as well as by sampling at the striking cup. As soon as the sample begins to show a slightly flaky condition, the purpose of superheating is accomplished. If superheating is continued beyond this point there is danger of "cracking" the product. The heat coagulation then causes the appearance of lumps of casein, robbing the product of its desired smoothness. This defect can be corrected as shown in Chapter XXVI, on "Defects of Unsweetened Condensed Milk" by passing the lumpy plain condensed milk through the homogenizer, which, however, involves extra labor and time.

Proper superheating requires experience and judgment on the part of the operator. No definite rule of temperature and time can be given that applies under all conditions. The character and concentration of the milk influence the heat coagulation point. For milk with a low heat coagulation point a temperature of 180° F. is usually ample. Milk with a high heat coagulation point may have to be heated to as high as 200° F. For similar reasons the time of superheating must be regulated in accordance with the behavior of the milk toward the heat. Obviously high acid milk, or milk the albumin content of which is excessive or that is profusely contaminated with bacteria producing rennet-like enzymes, or in which the salt balance is abnormal, or any other condition that causes the heat coagulation point to be low, will form a "liver" at lower superheating temperature and will "crack" more quickly than perfectly sweet milk and milk which is normal in every respect. For this same reason old milk, such as remnants or returns in market milk plants, which are generally disposed of in the form of plain condensed milk are apt to become lumpy during superheating unless the temperature and time of the process are carefully adjusted to the instability of the casein in such milk. The ratio of concentration also affects the heat coagulation point. The greater the concentration the lower the temperature at which the coagulum will form.

As soon as the superheating has produced the desired coagulum, the valve in the superheating steam line is closed, the vacuum pump is started up, water is supplied to the condenser and the pan is operated until the vacuum has returned to 25 to 26 inches and the temperature has dropped to 140° F. or lower. The product is then ready to be dropped out of the pan and cooled.

Cooling.—When the plain condensed milk comes from the pan, it should be cooled promptly to a low temperature and without excessive incorporation of air. This product is not sterile, nor does it contain sucrose to preserve it. In order to prevent souring and other fermentation it must be cooled to a temperature low enough to check or inhibit bacterial activity. It should be cooled to 40° F. or lower. The great viscosity of this product causes it to hold air that may be incorporated into it during cooling. This is objectionable because air hastens its deterioration and jeopardizes its quality. It also causes excessive shrinkage of the goods in storage, leaving the cans which were filled full after cooling, only partly full when ready for the trade.

The coil vat has proven highly serviceable for cooling plain condensed milk. The vat with vertical coil eliminates contact of the milk with bearings and glands and its revolving coil tends to expel rather than incorporate air. In the case of the horizontal coil vat air incorporation is greatly minimized by operating it sufficiently filled to have the milk cover the coil completely. Horizontal vats with the lower part constricted and the coil placed low in the constricted portion, so as to agitate the milk vigorously and to facilitate complete submersion of the coil, are particularly adapted for this purpose.

Because of the perishable nature of plain condensed milk the cooling equipment should be thoroughly washed and scalded with hot water and steam, or treated with a chlorine solution of suitable strength (100 p.p.m.) before each use.

When cooled the condensed milk is ready for the market. If held in the factory, it should be placed in a cold room, or should be otherwise protected against temperatures sufficiently high to cause it to sour. When kept at 40° F. or below the danger from souring is largely eliminated. If transported long distances during warm weather, it should be shipped in refrigerator cars.

SEMI-SOLID OR CONDENSED BUTTERMILK

Definition.—This product, known by the trade name "Semi-Solid Buttermilk" is creamery buttermilk, condensed at the ratio of approximately 3 to 3½ pounds of undiluted fluid buttermilk to one part of the semi-solid product.

Supply and Composition of Fluid Buttermilk.—The value of buttermilk as a part of the feed ration for chickens, laying hens, pigs and hogs has long been recognized and its use for feeding purposes is rapidly growing. Buttermilk not only contains protein and carbohydrates of high quality and great digestibility, but it has biological properties that stimulate growth and gain in weight, and it exerts a physiological action that makes for a healthy condition of the intestines, because of its lactic acid content.

Chicken feeders have found it invaluable in their efforts to accomplish maximum growth and gain in weight of the growing chicks, and because of the superior quality of the meat of buttermilk-fed fowl. And extensive experiments with laying hens have conclusively demonstrated that buttermilk makes for increased egg production.

For similar reasons buttermilk, when properly balanced with other feed, is a most valuable hog feed. In fact it is the foundation of a good hog and is becoming a more and more indispensable part of the ration for growing pigs and fattening hogs.

Table 19.—Composition of Buttermilk

Constituents in Buttermilk	From Ripened Cream					From Sweet Cream	
	Van Slyke %	Vieth %	Snyder %	Storch %	Fleischmann %	Storch %	Richmond %
Water	90.6	90.93	90.5	90.39	91.30	89.74	90.98
Fat	.1	.31	.2	.50	.50	1.21	.35
Casein	2.8	3.37	3.3	3.60	3.50	3.28	3.51
Albumin	.8						
Milk Sugar	4.4	4.58	5.3	4.06	4.00	4.98	4.42
Lactic Acid	.6			.75			.01
Ash	.7	.81	.7	.80	.70	.79	.73

Specific gravity of sweet-cream buttermilk 1.0331.

Specific gravity of sour-cream buttermilk 1.0314.

Caloric value 165.

Since the great bulk of butter is manufactured during the summer season, the main supply of buttermilk is confined to the summer months. In summer the output of buttermilk far exceeds the demand for this product and much of it goes to waste for lack of a suitable market. In winter, on the other hand, the output of buttermilk is small and often insufficient to supply the demand.

In order to stop this waste of buttermilk in summer, to utilize it economically and profitably and to equalize the supply throughout the year, some of the large creameries of the country have found it practicable and profitable to condense the surplus buttermilk. Information from chicken feeders and hog feeders show that, when re-diluted to the consistency of the original buttermilk, this condensed buttermilk gives equally as satisfactory results as the fresh buttermilk.

Manufacture.—There are several methods whereby buttermilk can be and is being commercially reduced in volume. The most common of these are, removal of water by gravity, removal of water by centrifugal separation, removal of water by evaporation, either in vacuo or under atmospheric pressure.

Removal of Whey by Gravity.—A portion of the so-called condensed buttermilk that reaches the market is not the result of evaporation of a portion of the water contained in the buttermilk, but is produced by permitting the curd to settle by gravity and then drawing off and rejecting the whey.

In this case the fluid buttermilk is pumped into a wooden tank, preferably a vertical stave tank. The tank usually contains several outlets with gates, located at different heights, to facilitate the removal of the whey. The tank may or may not be equipped with steam pipes for heating. The buttermilk is heated to boiling point in these tanks either by blowing "live" steam into it, or by passing steam through pipes installed in the tank. This heat is maintained for several hours. This causes the casein to contract and settle to the bottom in the form of fine particles of curd, leaving on top a clear whey. This whey is drawn off through the gates located above the stratum of curd. The residue, consisting largely of casein, water, some lactic acid, minerals and milk sugar, represents the condensed buttermilk. The reduction in volume thus produced, is at the ratio of about 4 to 5 parts of fluid buttermilk to one part of condensed buttermilk. It is obvious that in this form of concentration not all of the valuable food elements of the buttermilk are reclaimed. Most of the milk sugar and much of the lactic acid and minerals escape with the whey and are lost. However, the equipment required for this process is simple and inexpensive and the process requires no special knowledge on the part of the creamery personnel.

Concentration by Centrifugal Separation.—For many years efforts have been made to remove the water from the buttermilk by centrifugal separation. Machines are now on the market and in use, in which the curd of the buttermilk collects on the walls of a revolving basket while the whey is centrifuged out. These machines are similar in principle to the well-known laundry centrifuge. They have been successfully used by creameries that are engaged in the manufacture of buttermilk cheese. Their operation, however, is intermittent only. When the basket fills up with the curd, the machine must be stopped and the curd removed.

For the purpose of handling large volumes of buttermilk daily, these centrifuges are obviously not well adapted. They are too limited in capacity, in speed and in volume of performance. Efforts to devise a centrifuge for continuous operation, similar to the cream separator, have so far failed. The specific gravity of the curd in the buttermilk is so nearly like that of the whey, that the centrifugal separator refuses to discharge a liquid rich in curd and one of practically clear whey. Experiments by the author have demonstrated that, no matter how the outlets of the separator bowl are adjusted, both discharges have practically the same composition.

Evaporation in Vacuo.—This method for condensing buttermilk is rapidly gaining in favor and today vast volumes of buttermilk are concentrated in this manner. Equipment and method of operation are principally the same as those used in the manufacture of condensed milk and evaporated milk. The buttermilk is condensed in the vacuum pan.

Equipment Necessary to Condense from 5,000 to 6,000 Pounds of Buttermilk per Hour:

2 wooden buttermilk storage tanks, capacity 10,000 pounds each, for ripening the buttermilk;

1 6-foot vacuum pan with condenser;

1 vacuum pump, vacuum cylinder 18-inch diameter and 20 inches long; if steam driven, steam cylinder, 12-inch diameter and 12-inch stroke;

2 hot wells, 5-foot diameter and 5 feet deep, with 3-inch outlet in bottom, and equipped with brass heater arrangement.

Boiler capacity, 150 H. P.

Water requirements, 125 gallons per minute.

OPERATION

Ripening of Buttermilk.—The buttermilk should be sour, the sourer the better, because:

1. High acid content is necessary to prevent the appear-

ance of lumpy and granular curd in the finished product. Acid concentrations over 1 per cent lactic acid have a solvent effect on the casein. They make possible the heating of the buttermilk without coagulation, thus yielding a condensed buttermilk with smooth texture.

2. High acid content is necessary in order to give the condensed buttermilk satisfactory keeping quality. The finished product is not sterile, nor is the temperature at which it is held in storage sufficiently low to inhibit bacterial action and prevent decomposition. High acidity is essential to preserve this product.

3. High acid is advantageous for feeding purposes. The acid in the buttermilk keeps the fowls, pigs and hogs in healthy condition, and makes them thirsty. They drink more water, which is a valuable asset for best results.

To accomplish these purposes the fluid buttermilk, before condensing, should have an acidity of about 1.5 per cent or more, calculated as lactic acid. The great bulk of commercial creamery buttermilk has a much lower acidity and, therefore, has to be soured or ripened before condensing. For this purpose it is heated to about 85° F. to 95° F. and held for 24 hours, or longer, in wooden storage tanks. The ripening is hastened by the use of a lactic acid starter. In commercial practice this is usually provided by leaving a remnant of about 100 gallons of soured buttermilk of the previous batch in each storage tank. This remnant serves as a starter for the succeeding batch that is held in the storage tank.

Much of the semi-solid buttermilk is now made to contain approximately 6 per cent acid, the higher acid being preferred because of improved body, smoother texture, and better keeping quality of the finished product. This is accomplished by the use of B. bulgaricus cultures and temperatures of 105 to 110° F. for ripening, whereby the acidity of the uncondensed buttermilk can be developed to near 2. per cent.

The storage tanks in which the buttermilk is soured are usually also provided with an air supply pipe for the purpose of agitating the buttermilk before it is pumped over into the preheater or forewarmer. The heavier curd tends to settle to the bottom during the ripening period and there is a tendency for the buttermilk to whey off. By blowing air through the buttermilk before transferring it to the forewarmer, the product is mixed and made reasonably homogeneous, thus equalizing the composition of the batches and facilitating their handling in the pan.

It occasionally happens in the routine of manufacture that acid development is slower than normal. This is usually due to the starter having lost its vigor, or too small an amount of starter having been used, or the temperature of the buttermilk having dropped below the optimum for proper ripening, etc. These factors can usually be adjusted to insure normal ripening of succeeding batches and the acidity of any low-acid batches may be developed to the desired point by adding more starter if available, or by raising the temperature and prolonging the ripening process.

However, when the time set for forewarming and condensing has arrived, the factory routine does not always permit of extending the period of ripening. The tanks may be needed for new buttermilk and must be emptied. In such situations the objectionable consequences of forewarming and condensing insufficiently ripened buttermilk may be avoided by the addition of enough acid to the buttermilk to bring the acid test up to the desired point. For this purpose commercial lactic acid is preferred, but other similar organic acids may be used. Mineral acids, such as hydrochloric or sulphuric should not be used. The added acid should be well mixed with the buttermilk in the tank by means of vigorous agitation. The buttermilk is then ready for forewarming and condensing in the normal manner.

Forewarming the Buttermilk.—From the storage tanks the ripened buttermilk is transferred to the hot wells, where it is heated to near the boiling point. The heating is generally done in plain forewarmers by turning "live steam" into the buttermilk. As explained in Chapter IV, this system of forewarming is very crude from the standpoint of economy of steam, because the steam condenses in the milk, increasing its volume by about one-sixth of its original volume and therefore increasing the amount of water that has to be evaporated in the pan.

However, to heat the buttermilk with "live steam" has the advantage of keeping it well agitated, thereby preventing the copious settling of the curd and assuring the feeding of the pan with a product of reasonably uniform composition. This is further facilitated by keeping the steam valve at the forewarmer slightly open while the heated buttermilk is drawn into the pan.

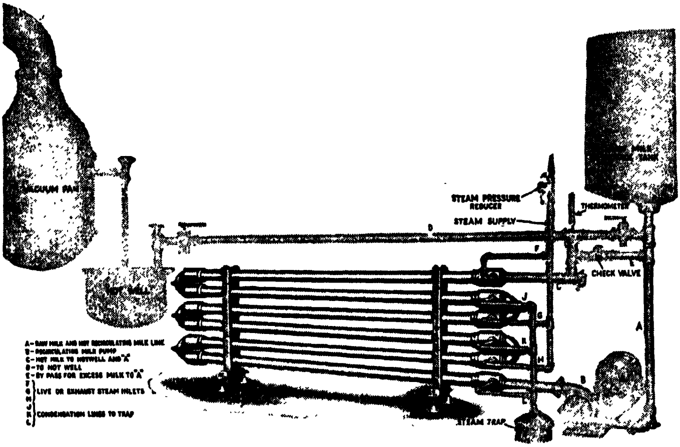
VACUUM PAN
HOT WELL
STEAM PRESSURE REDUCER
STEAM SUPPLY
THERMOMETER
MILK TANK
CHECK VALVE
STEAM TRAP
A
B
C
D
E
F
G
H
J
K
L
A–RAW MILK AND HOT RECIRCULATING MILK LINE
B–RECIRCULATING MILK PUMP
C–HOT MILK TO HOTWELL AND "A"
D–TO HOT WELL
E–BY PASS FOR EXCESS MILK TO "A"
F G H LIVE OR EXHAUST STEAM INLETS
J K L CONDENSATION LINES TO TRAP

Fig. 87. Recirculating unit for forewarming buttermilk
Courtesy of Jensen Creamery Machinery Co.

Condensing the Buttermilk.—The hot buttermilk is drawn into the vacuum pan. The operation of the pan is similar to that described in Chapter VIII. On account of the high acidity of the ripened buttermilk, pans tinned or glass-lined on the inside or constructed of stainless steel would be preferable to pans with plain copper surfaces exposed to the milk, as the combined influence of high temperature and high acidity intensifies the action of the milk on the copper. The tinning of copper pans, however, has been abandoned, because of the very short life of the tin coating in the case of pans used for buttermilk condensing, while the higher cost of the metals more resistant to corrosion, such as glass lined steel and stainless steel, is retarding the use of vacuum pans constructed of these metals.

During the early stages of the condensing process the buttermilk boils and behaves in the pan in a manner similar to milk. As the process continues and the buttermilk increases in density, it becomes more sluggish and does not circulate as rapidly, nor boil as vigorously. The buttermilk is condensed to a concentration of approximately 27 to 28 per cent total solids.

Testing for Density.—To determine the point when the buttermilk has been condensed to the desired per cent of total solids is somewhat difficult. This is partly due to the variable composition of the original buttermilk and to the viscosity of the condensed product when it approaches the desired degree of concentration. It is too thick and viscous to readily respond to the use of the Baumé hydrometer.

Ordinarily, however, the determination of the proper degree of concentration is left to the experienced eye and judgment of the pan operator. If he condenses batches of uniform size, the height of the surface of the condensed buttermilk in the pan furnishes an approximate guide. The behavior of the boiling condensed buttermilk, when the proper degree of concentration has been reached, is also noted. And samples taken from the pan and examined for thickness, standing-up properties and transparency or opaqueness, as described under "Methods of Striking" for sweetened condensed milk, Chapter VIII, enable the operator to approach a fairly uniform density of the finished product from batch to batch.

When condensed at the ratio of 4:1 the buttermilk at the temperature of the pan, or about 120° F., is thick enough so that when a sample is taken into a cup and a portion of it is picked up with a spoon or stick and is allowed to drop back into the cup from a height of about six inches, it does not readily diffuse, but "piles up" on the surface of the sample in the cup.

For more accurate work the density may be determined by weighing a definitely measured volume of the product at a given temperature. For this purpose a cone-shaped cup, such as was designed by A. O. Dahlberg and improved by F. R. Evans[97] for the purpose of determining the specific gravity of sweetened condensed milk, may be used to advantage.

This cup is illustrated in Fig. 88. It consists of a cone-shaped copper cup, holding 100 cc. In order to permit of reasonably rapid filling without spilling over the outside of the cup, a removable top is provided. This top consists of a circular disk with a circular hole in the center just large enough to fit over the top of the cup. On the underside is a collar fitting closely around the neck of the cup and holding the upper surface of the disk even with the mouth of the cup. The joint between disk and cup is tight. The disk is of sufficient size to allow any milk dripping over the edge to fall clear.

When ready to take a sample the removable top is placed upon the cup and the cup is filled directly from the pan until the milk overflows on to the disk. Then the excess milk is removed with a knife or spatula, the top is removed and the cup with contents is placed on scales, sensitive to 0.1 grams. By the use of such a device and an accurate test room balance, counter balanced with the weight of the empty cup, the weight of 100 cc. of condensed buttermilk may be determined rapidly and accurately. In case of foam in the milk, the foam may be readily floated off over the top.

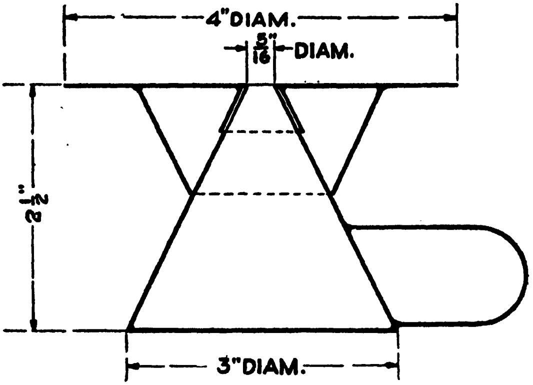

Fig. 88. Density tester

Table 20.—Weight of 100 cc. of Condensed Buttermilk of Various Percentages of Total Solids

Per Cent Total Solids	Weight of 100 cc. Condensed Buttermilk				
	100° F.	110° F.	120° F.	130° F.	140° F.
25% solids.........	107.5	107.2	106.9	106.5	106.2
26% solids.........	107.8	107.4	107.1	106.7	106.4
27% solids.........	108.0	107.6	107.4	106.9	106.5
28% solids.........	108.3	107.9	107.6	107.1	106.7
29% solids.........	108.6	108.1	107.8	107.4	106.9
30% solids.........	108.8	108.4	108.0	107.6	107.1
31% solids.........	109.0	108.6	108.3	107.8	107.3
32% solids.........	109.3	108.8	108.5	108.0	107.5

From the weight of the contents of the cup thus determined the per cent total solids in the condensed buttermilk may be found at temperatures ranging from 100 to 140° F. by consulting Table 20.

Condensing Buttermilk by Film Process.—The condensing of buttermilk can be and is accomplished also by film evaporation by the use of the "Continuous Concentrator," as explained in Chapter XIX. These atmospheric evaporators are of advantage to creameries with limited output, whose volume of buttermilk is too small to justify the installation and operation of vacuum equipment. The fact that the atmospheric evaporators require no water for condensing is an additional advantage.

Lime Deposits in Semi-Solid Buttermilk.—Barrels in which the semi-solid buttermilk has been stored, often show large quantities of lime compounds, shaped similar to stalactite cones. These deposits are usually most noticeable in the case of buttermilk made from high-acid cream that was neutralized with lime. So far no satisfactory means has been found for preventing this, except that of eliminating lime as a cream neutralizer for buttermaking.

Utilizing Skimmilk in the Manufacture of Semi-Solid Buttermilk.—For detailed directions of using skimmilk, see succeeding paragraphs in this chapter under "Concentrated Sour Skimmilk."

Packing.—The condensed buttermilk is not cooled for packing. It is filled into barrels direct from the pan or other evaporator. The barrels hold approximately 50 gallons or about 475 lbs. of semi-solid buttermilk. Second-hand glucose barrels or copra barrels are generally used for this purpose. Buttermilk intended for bakeries, confectioneries and other channels of human consumption is filled into new barrels. The barrels should be thoroughly rinsed and steamed out before filling and it is advisable to treat them on the inside with sodium silicate.

A limited amount of condensed buttermilk is also packed in hermetically sealed tins for household purposes. The tins vary in size from 16 ounces to one gallon. Condensed buttermilk so put up keeps well and has been found very useful for diverse culinary purposes. It contains all the valuable food elements of milk except butterfat and its high content of lactic acid adds to its wholesomeness.

Storage.—The barrels and tins of condensed buttermilk are stored at ordinary temperature. If made from properly soured buttermilk, condensed at the ratio of 4:1, and if the package is filled full and sealed tightly, this product will keep. It must contain not less than 3.5 per cent and preferably as high as 6 per cent of acid, calculated as lactic acid. This high acidity is necessary to prevent deterioration and molding.

In remnant barrels or in barrels from which a portion of the contents has been removed, the buttermilk molds rapidly on the surface and spoils, because of exposure to air. This can be largely prevented by "slapping" a piece of heavy paper (wrapping paper), large enough to cover the entire exposed surface, on the top of the remaining contents. The condensed buttermilk being of a pasty consistency forms a tight seal with the paper, shutting out the air, and retarding molding and decomposition.

The above statements concerning the keeping quality of condensed buttermilk refer only to the product resulting from evaporation of a portion of the water, such as condensing in the vacuum pan, or by the continuous concentrators and evaporators. Where the reduction in volume is accomplished by removing a portion of the whey, either by gravity or by centrifugal separation, the finished product lacks in keeping quality; it will spoil in a few weeks after manufacture, if held at ordinary temperatures. The reason for this lies in the fact that with the removal of the

Table 21.—Composition of Commercial Condensed Buttermilk

	Sample No.					
	1	2	3	4*	5*	6*
	%	%	%	%	%	%
Water	69.00	73.50	70.80	71.30	67.30	75.00
Fat	2.30	1.00	1.30	2.60	2.30	2.20
Protein	10.80	9.00	9.90	11.85	11.59	11.38
Milk sugar	12.00	9.80	11.70	4.40	5.67	3.96
Ash	2.20	1.70	2.00	4.40	7.51	2.92
Lactic acid	4.50	5.00	4.30	6.30	6.01	6.19
Total solids	31.80	26.50	29.20	28.70	32.70	25.00

*Analyses by Mohr and Schulz.[101]

whey, the finished product is also deprived of much of the lactic acid. There is not high enough a percentage of acid left in it to preserve it.

Yield of Semi-Solid Buttermilk.—The yield of condensed buttermilk obviously varies with the per cent total solids in the fluid and the condensed product. The total solids in the finished product vary between about 25 and 33 per cent. Average commercial condensed buttermilk, as now manufactured, contains about 27 to 28 per cent total solids.

The total solids in fluid buttermilk that has suffered no dilution with water amount to approximately 8.7 to 9.0 per cent. On the basis of the above figures and assuming the total absence of mechanical losses, 100 pounds of fluid buttermilk would yield from 30 to 33 pounds of condensed buttermilk.

In commercial operation, however, this high yield is not attained. This is largely due to the fact that the per cent solids in the great bulk of creamery buttermilk is considerably lower, because of dilution with water. There is more or less unavoidable admixture of water to the cream between the farm separator and the churn. Under ordinary conditions of operation the creamery buttermilk averages about 7.25 to 7.75 per cent total solids and the yield of condensed buttermilk is approximately 25 pounds per 100 pounds of fluid buttermilk.

Markets of Semi-Solid Buttermilk.—Limited amounts of condensed buttermilk pass into channels of human consumption, through the medium of bakeries, confectioneries and grocery stores. The basic commercial market for this product, however, lies in its demand for stock feed.

The great bulk of its annual output goes to stockfeed mills, and to feeders of pigs, hogs and poultry. Its use for these purposes has demonstrated its value as a stock feed. It is highly relished and readily digested. It is nutritious and its high acid content acts as a tonic and assists in keeping animal and fowl in healthy condition. It accelerates the power of assimilation of other feeds in the ration, thereby augmenting their digestibility and their economy as feeds, and giving the animal greater capacity for the consumption of feed and water.

The price of semi-solid buttermilk varies with season, locality, supply and demand, ranging in normal times approximately from 3 to 5 cents per pound for stock feeding purposes. That furnished to bakeries and other prepared food manufacturers ranges from about 6 to 8.5 cents per pound.

The rapid growth of the manufacture of condensed buttermilk in the United States is shown statistically in the following table:

Table 22.—Annual Output of Condensed Buttermilk in the U. S. for the Years 1918-1932

Year	Total Volume of Uncondensed Buttermilk[1]	Total Manufacture of Condensed Buttermilk[2]	Buttermilk Utilized for Condensed Buttermilk[1]
	Pounds	Pounds	Per Cent
1918	1,209,000,000	6,534,023	2.16
1919	1,327,980,000	22,535,580	6.79
1920	1,347,180,000	32,539,000	9.66
1921	1,645,703,000	29,314,000	7.12
1922	1,799,483,000	44,343,000	9.86
1923	1,953,453,000	54,833,000	11.23
1924	2,115,484,000	66,837,000	12.63
1925	2,123,981,000	77,079,000	14.52
1926	2,264,755,000	86,687,000	15.31
1927	2,334,532,000	99,180,000	16.99
1928	2,319,796,000	102,452,000	17.67
1929	2,491,362,000	107,288,000	17.23
1930	2,488,560,000	96,431,000	15.50
1931	2,601,225,000	64,619,000	9 93
1932	2,642,846,000	52,167,000	7.89

[1] Calculated on basis of 1.56 lbs. buttermilk per pound of butter.

[2] Buttermilk concentration 4:1.

CONCENTRATED SOUR SKIMMILK

Definition.—This product is very similar in composition, character and properties to semi-solid buttermilk. Its purpose is to convert the surplus of skimmilk at the creamery and especially at the market milk plant, for the disposition of which there is often no profitable nearby market, into a product less bulky and more stable. This makes possible, economical storage from the time of surplus to the time of shortage, and transportation to distant markets, without danger of spoilage.

Uses.—Concentrated sour skimmilk is a comparatively new product, but on account of its high value as a feed for poultry and hogs the annual market demand for this product has increased rapidly and its production in 1931 reached 27,611,000 lbs. Feeding experiments as well as commercial feeding results have demonstrated that it improves the quality of the meat and accomplishes cheaper gain in weight and cheaper eggs. Like semi-solid buttermilk, it also improves the physical condition of fowl and swine and is effective in combating disease.

Importance of Acid Development.—The development of high acidity in the fluid skimmilk is all important in the successful manufacture of concentrated sour skimmilk. An acidity of .7 per cent to 1 per cent to which souring with the ordinary lactic acid bacteria, such as S. lactis, is limited, is inadequate for the purpose of this product. Skimmilk of this relatively low acidity becomes lumpy when heated to condensing temperatures, the casein forming large masses and burns on the heating coils in the vacuum pan. Likewise, the concentration cannot be carried far enough to have the acid content of the finished product sufficiently high to prevent the damaging growth of bacteria, yeasts and molds. While the lumpiness could be corrected in part at least, by mechanical means of breaking up the curd, such as churning or homogenizing, the extra equipment and operations required would considerably increase the cost of manufacture.

The above objections of lumpiness and lack of keeping quality may be eliminated readily and completely by the use of special cultures capable of developing in the fluid skimmilk an acidity of 1.7 per cent or higher. This high acid concentration has a solvent action on the precipitated casein which solvent action increases during evaporation of a portion of the water in the pan. Condensing skimmilk that has an acidity of 1.70% or over eliminates pan operating difficulties and produces a concentrated skimmilk of an admirable, smooth texture with a sufficiently high acid content to inhibit bacterial growth and to prevent deterioration after manufacture.

The process of manufacturing concentrated sour skimmilk was developed and patented by Rogers[98] in 1923, who generously dedicated it to the public, thus making it available to the dairy industry without restrictions. In a later publication Rogers, Johnson and Albery[90] described the process of manufacture in detail. It is briefly as follows:

Culture Used.—A mixed culture of Bacillus bulgaricus and a mycoderm is used. Propagate the culture at a temperature range of 105 to 110° F. Inoculate a quart jar of sterilized milk with a teaspoonful of this culture. When inoculated late in the afternoon and held overnight at the above temperature the mother culture in the jar usually is curdled with a high acidity by the following morning. This mother starter is now ready for inoculation of the "big" starter, which later is to be added to the skim milk to be soured and concentrated.

"Big" Starter.—The big starter is prepared as follows: Use enough skimmilk for the big starter to have available a quantity of starter equal to 1 to 2% of the skimmilk to be soured and concentrated. Heat the starter skimmilk to 180° F. or above, for at least a half hour, care being taken that all the milk reaches this temperature. Use an ordinary starter can or vat for this purpose. Then cool to 115° F., add the mother starter from the quart jar and agitate for 5 to 10 minutes. Hold the starter at a temperature of 100 to 110° F. and time the inoculation so that the starter is still in the actively growing stage when it is added to the batch of skimmilk. An old starter will be slow in starting the fermentation. The starter is in most active condition at the time of curdling.

Souring the Batch.—Pasteurize the skimmilk, either by flash process at 180° F. or by vat process preferably at 150 to 160° F. for 30 minutes. High temperature pasteurization is desirable not only to destroy objectionable bacteria but also because these high temperatures tend to yield a smoother texture in the finished product.

Ripening vats or tanks should be provided with agitators and facilities for heating and cooling. Metal surfaces should be avoided. Even tin will discolor and corrode when exposed to the combined action of high acid and high temperature. Glass-lined tanks and cypress vats are recommended.

Cool the pasteurized milk to 115° F., add 2% of starter. The starter should be added slowly and while the milk is being agitated, otherwise lumps will form due to intense localized curdling action.

Adjust the ripening conditions so as to allow a drop in temperature of not more than 10° F. in 18 hours. At the end of this period the acidity of the milk should be between 1.7% and 2.0% lactic acid. For operation of the acid test see Chapter XXXVII.

Condensing the Sour Skimmilk.—Break up the curd as thoroughly as is possible with ordinary coils or other mechanical agitators. Do not preheat. Draw the sour skimmilk into the vacuum pan at the temperature at which it was held in the vat. Forewarming hardens the lumps of curd and makes a rough texture in the finished product. If the acidity of the milk before concentrating is high enough (1.7% to 2.0%) there is no difficulty from lumping in the pan or burning onto the pan coils.

For dependable keeping quality the acidity in the finished product should be not less than 5% and preferably 6%. The acidity in the finished product depends, aside from the acidity in the uncondensed milk, on the concentration of the milk solids.

"Striking," or Determination of Density.—This product has a very thick, sluggish body. Its degree of concentration or density cannot be determined by the use of hydrometers such as the Baumé type.

A simple and reasonably accurate method is that of titrating for acidity. The acidity increases very nearly in direct relation to the concentration. The acidity may be conveniently tested as follows:

Transfer 9 grams of the finished product into a tared white titrating dish on scales. Add from 20 to 30 cc. of distilled water, and 5 drops of phenolphthalein indicator. From burette run $\frac{N}{10}$ sodium hydroxide solution into the titrating dish while constantly stirring the sample. When the sample takes on a permanant, light pink color enough alkali solution has been added. The number of cc. alkali solution required as shown by the burette divided by 10 represents the per cent acid in the sample. The per cent acid of the finished product divided by the per cent acid of the uncondensed soured skimmilk gives the ratio of concentration. The per cent solids of the uncondensed skimmilk multiplied by the ratio of concentration gives the per cent solids of the finished product.

Example:

The uncondensed skimmilk contains 9.2% solids and 2% acid. The concentrated skimmilk tests 6% acid. What is the ratio of concentration? What is the per cent milk solids in the finished product?

Answer:

Ratio of concentration is $\frac{6}{2} = 3:1$.

Percent solids in finished product is $9.2 \times 3 = 27.6\%$.

If it is desired to attain a definite per cent solids in the finished product, the condensing process should be continued until the acidity has reached the desired concentration.

To determine the acidity required that corresponds to the desired per cent solids in the finished product, divide the per cent solids desired in the condensed milk by the per cent solids in the unconcentrated milk and multiply with the per cent acid in the unconcentrated milk. This gives the acidity required in the finished product.

Example:

Solids desired in finished product	28 %
Solids contained in fluid skimmilk	9 %
Acid in fluid skimmilk	1.9%

What is the correct acidity of the finished product?

Answer:

$\frac{28 \times 1.9}{9} = 5.9\%$ acid needed in finished product to bring solids up to 28%.

The concentration may be determined also by the picnometer method, illustrated and described under "Semi-Solid Buttermilk." This method gives the weight of a 100 cc. sample as compared with the weight of the same volume of water. In the absence of accurate weight figures of concentrated sour skimmilk the weight figures of semi-solid buttermilk of different percentages of solids as shown in Table 26 may serve the purpose. It should be understood, however, that the figures in Table 26 were intended for semi-solid buttermilk only. Their accuracy when applied to concentrated skimmilk has not been determined. The objection to this method lies in the difficulty of filling the flask quickly without incorporating air which interferes with the accuracy of the weight.

Still another method recommended is the determination of the refractive index. The refractive index of the serum varies directly with the concentration of the soluble solids and the relation of these constituents to the total solids has been found to be nearly constant. While the refractometer required is somewhat expensive, its operation is simple, and determinations can be made quickly. A little clear serum is obtained by pressing a small sample of the milk in a fine mesh cloth. A few drops of this serum are placed between the plates of the refractometer and the refractive index is read. If the correct refractive index for a batch with the required per cent of solids is known, it is then only necessary to continue evaporation until the refractive index coincides with that of the standard batch.

Rogers recommends that the concentration be carried to about 28% solids. At this point the finished product flows freely from the pan, and has a thick pasty consistency when cold.

Packing Concentrated Sour Skimmilk.—It is filled into barrels direct from the pan without cooling. The barrels used are usually similar to glucose barrels, made of oak or fir and with a capacity slightly over 500 pounds. The barrels should be airtight. Leaks are objectionable, not only because of loss of contents but they admit air and invite damaging mold growth. They are preferably paraffined or coated with sodium silicate. This is especially desirable in case of second-hand barrels.

This concentrated sour skimmilk, when properly made and packed, and containing above 5 per cent acid, will keep indefinitely without cold storage, unless its surface is exposed to the air, in which case molds will develop.

The Rogers' process, as described above, was later subjected to extensive experimental study by Mohr[100] and Mohr and Schulz[101] whose results fully confirm the findings of Rogers et al. Mohr used cultures of Thermobacterium Jugurt (Jensen) for ripening the skimmilk to the high acidity required. He, too, found it necessary to develop an acidity in the uncondensed milk of approximately 2% calculated as lactic acid. He emphasizes the advantages of high-temperature pasteurization for optimum smoothness and consistency of the finished product, and secured the best results when heating for 10 minutes at 100° C. (212° F.). He likewise found that forewarming before condensing is not necessary nor desirable and suggests that, in order to avoid the danger of objectionable wheying-off, the temperature in the vacuum pan should be held below 70° C. 158° F.). Since, under normal conditions of condensing, the pan temperature is around 130 to 145° F., the danger of excessive pan temperature is indeed negligible.

Mohr further studied the effect of homogenizing the soured uncondensed product and reports that homogenization of the soured skimmilk caused the concentrated product to be grainy. At an acidity of 1% or below in the fluid milk the grain in the finished product was coarse; an acidity of 2% also yielded a grainy product but the grain was finer. Homogenization is obviously not needed nor helpful in the manufacture of this product.

Keeping Quality of Concentrated Sour Skimmilk.—Rogers showed that, when properly made, and when the finished product has an acidity above 5% (preferably 6% or slightly over) the sour concentrated milk will keep indefinitely without appreciable change. No abnormal fermentations will develop even at summer temperatures so long as the surface is not exposed to air. When the surface is exposed to air molds will develop, as in the case of semi-solid buttermilk held under similar conditions. Concentrated sour skimmilk does not freeze at ordinary winter temperatures.

Mohr and Schulz endeavored to improve the product and its keeping quality by the addition of freshly slaked lime ($Ca [OH]_2$), chalk ($CaCO_3$), salt ($NaCl$), and sodium citrate ($2Na_3 C_6H_5O_7 . 11 H_2O$), respectively. These additions, however, failed to improve the keeping quality and the finished product containing these added chemicals showed a greater tendency toward wheying-off. Their use, therefore, is of no value. It is not improbable that, in the case of using lime or chalk, prolonged holding of the finished product in the above experiments would have developed large stalactite cone-like deposits of lime compounds, such as frequently form in semi-solid buttermilk, made from the fluid buttermilk of high-acid, lime-neutralized cream.

Experiments in which the surface of the finished product held in open containers was covered with layers of lactic acid (9% solution), acetic acid (6% solution), and paraffin, respectively, showed the following results:

Lactic acid failed to prevent mold formation.

Acetic acid prevented mold formation.

Paraffin prevented mold formation.

The exposed surface of concentrated sour skimmilk molded more when kept in the dark than when exposed to daylight.

The above results are interesting in that they confirm the experience over a prolonged period of time in the commercial manufacture in the United States of both semi-solid buttermilk and concentrated sour skimmilk. This experience has amply demonstrated that it is the surface of the product in broken or remnant containers only, that is subject to mold formation. When the containers—the barrels or tins—are completely filled and sealed in accordance with the usual commercial practice, the exclusion of air is sufficient to avoid all danger of spoilage. Sealing the surface with a layer of acid or paraffin would be of added protection only in the case of broken or remnant packages, if practicable. Under commercial conditions the simplest, most effective and most economical means of protecting remnant packages against mold development is to completely cover the exposed surface with a piece of heavy packing paper, pressing the paper well into the surface layer of the concentrated product, so as to make intimate contact between paper and milk product and to thus exclude the air.

Marketing.—In normal times the market price of barrelled goods in car lots has been about 3 cents per pound at the factory and up to 4 cents in small packages, such as in friction top tin cans.

The cost has been estimated at 1½ cents and the package in the case of barrels should not exceed ¼ cent per pound.

One hundred pounds of average skimmilk will yield about 33 pounds of concentrated sour skimmilk containing 28 per cent solids. Placing the manufacturing cost at 2 cents inclusive of package, and the sales price F.O.B. factory at 3 cents per pound, the net returns would be 33 cents per 100 pounds of fluid skimmilk.

CHAPTER XIX

CONDENSING BY CONTINUOUS PROCESS

Purpose.—The continuous system of condensing milk offers numerous distinct advantages over the batch system. It increases the capacity of the equipment, it reduces the amount of equipment needed, it eliminates much of the time-labor-and fuel-consuming operation of starting and finishing the batch and loss of time between batches. It facilitates the manufacture of a uniform product.

With the trend of the industry toward fewer and larger factories and larger volume in each factory operated, the trend in method of manufacture is away from the batch principle and toward the principle of the continuous system. It is in the handling of large volume where the continuous system operates most advantageously.

Formerly milk condensing by the continuous system was practically entirely limited to the use of the continuous concentrator in which evaporation proceeds under atmospheric pressure. Today the continuous system is applied to vacuum pan operation as well. In the United States this system has largely superceded the batch system in the manufacture of evaporated milk in factories with large production.

Vacuum Pan Operation by the Continuous System.—The operation of the vacuum pan with continuous discharge applies to the manufacture of unsweetened condensed milk (evaporated milk) only. It does not lend itself advantageously to the manufacture of sweetened condensed milk, because of the difficulty of apportioning the added sugar uniformly throughout the period of condensing and because of the absence of a satisfactory method for the accurate and continuous determination of the density of this viscous product.

In the case of evaporated milk the pan discharge is bypassed back into the vacuum pan until the desired density has been attained, as indicated by the continuous density tester. When the milk in the pan has reached the proper operating level and the pan discharge shows the desired concentration, the milk intake to the pan is adjusted to maintain a uniform level of milk in the pan and to cause the pan discharge to be uniform in density, i.e., the milk intake is adjusted to the rate of evaporation.

In order to accomplish this the pan discharge is connected with a suitable centrifugal pump of a capacity approximately 30 per cent in excess of the desired discharge. In order for this pump to function satisfactorily, its stuffing box must be water-sealed and the pump should be installed several feet below the bottom outlet of the pan.

The discharge pipe extends from the pump upward to a convenient height above the vacuum pan platform for operating the discharge and re-circulating valve. It is equipped with a by-pass that enters the pan above the milk level.

The pump discharges a continuous flow of milk; its suction and discharge are never throttled; it has no valves to reduce the milk flow; it always has a full-flow discharge. If the milk is not of sufficient concentration, its density is increased, not by reducing the discharge, but by by-passing more milk back into the pan. A suitable arrangement for vacuum pan operation by the continuous process is shown in Fig. 66.

The Continuous Density Tester.—The discharge pipe feeds the continuous density tester and flows to the supply tank of the homogenizer. The continuous density tester is installed at a level approximately even with the eye of the operator on the pan platform. The milk enters the bottom of the tester and its overflow returns direct to the pan through a float-operated valve. A Baumé hydrometer floats freely in the continuous flow of the tester, indicating the density of the evaporated milk, which is readily observed from the pan platform. The proper density is controlled by regulation of the by-pass valve. If the density is too low, more milk is by-passed back into the pan; if it is too high the by-pass is reduced. The level of the milk in the pan is controlled by the volume of the fluid milk intake.

The Automatic Density Tester.—For automatic density control, the density tester may be combined with a photo-electric cell. This cell makes contact with and regulates the steam flow to the coils, or the by-pass valve, or the discharge valve, or the milk inlet, or two or more of these density-controlling accessories. By this system the density of the finished product can be controlled automatically so accurately as to eliminate the necessity of subsequent standardization.

THE CONTINUOUS CONCENTRATOR

Principle of Continuous Concentrator.—This machine condenses the milk under atmospheric pressure at a temperature of approximately 212° F. It operates on the basis of the film principle of evaporation. The inflow of fluid milk and the discharge of condensed milk are continuous. A rapidly revolving agitator impinges a thin film of milk against the steam-heated periphery of a stationary, jacketed copper drum. The agitator blades remove the milk film continuously and keep the heating surface clean and brightly polished. The high velocity of the milk and the continuously polished heating surface augment the rapidity of heat transmission, inducing rapid evaporation.

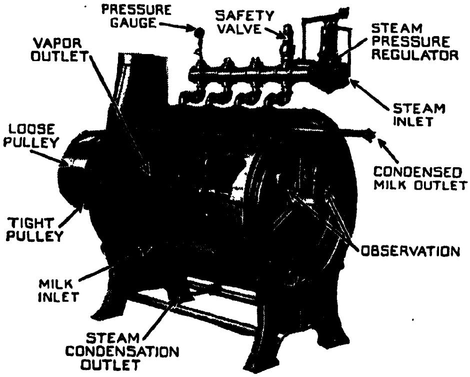

Fig. 89. The continuous concentrator
Courtesy of Creamery Package Mfg. Co.

Description of Continuous Concentrator.—This machine consists of a hollow, steam-jacketed copper drum. The space between inner shell and outer jacket is approximately one inch. The steam jacket is insulated. The drum carries in its interior a revolving dasher or spider web with four or more blades, according to diameter of drum. The blade edges contact with the periphery of the drum. When in operation each blade constantly removes the concentrated film of milk that forms on the heating surface.

The blades are pressed against the heating surface by the centrifugal force generated by the rapidly revolving dasher. The arms to which the blades are attached are equipped with stops that control their pressure against the heating surface. This insures continuous and uniform pressure, thus providing rapid and complete removal of the milk film from all parts of the steam heated drum surface. The shaft on which the dasher arms are mounted runs lengthwise through the center of the drum and passes through the front and rear heads of the concentrator. The power is transmitted to a pulley on the rear end of the shaft.

The rear of the concentrator terminates in an exhaust chamber and galvanized iron flue through which the milk vapors escape to the outside. The vapors are not condensed, but discharge into the atmosphere. The rear end of the drum is equipped with the milk intake which is located at the bottom, thus permitting gravity feed without necessitating an inconveniently high elevation of the forewarmer. The front head of the drum carries the condensed milk discharge. This is located in close proximity to the periphery of the drum. Its position is adjustable. Its distance from the inner drum surface determines the thickness of the milk film, the consistency of the finished product, the amount of superheating the milk receives and the amount of milk retained in the machine during operation. According to the amount of superheating desired the thickness of the milk film may vary from 1/8 to 1/2 inch and the amount of milk retained from 6 to 12 quarts.

The front head of the drum is also equipped with a spy glass for observing the interior during operation. The front head is removable, being fastened to the drum with screw bolts, and permitting the ready removal of the dasher and blades. Over the top of the concentrator extends the main steam line, a 3″ diameter pipe with sufficient 1½″ laterals to supply the jacket with uniform distribution of steam. The steam line is also equipped with pressure regulator and steam gauge. At the bottom of the concentrator is located the steam exhaust and regulating drip valve, or trap.

The continuous concentrator is constructed of diverse sizes and capacities, the most common of these sizes are the following:

Diameter	Length	Capacity per hour when concentrating at the ratio of 3:1	Boiler Capacity Required
3 feet	4 feet	4000 lbs.	100 H. P.
3 feet	3 feet	3000 lbs.	75 H. P.
3 feet	2 feet	2000 lbs.	50 H. P.

Speed of Agitator.—The proper speed of the continuous concentrator is expressed in terms of peripheral or rim speed, that is the distance which the blades travel per minute. It has been found that the rim speed which is sufficient to move the film of milk in the machine properly, is about 2500 feet per minute. In order to insure a rim speed of 2500 feet per minute, the blades in a 3-foot diameter machine must revolve $\frac{2500}{3 \times 3.14} =$ 265 times per minute. In a 6-foot diameter wheel, the same rim speed would require $\frac{2500}{6 \times 3.14} = 133$ revolutions per minute of the spider.

Again, it has been found that the blades should be not more than about 2½ feet apart. A three foot diameter concentrator, therefore, requires four blades while concentrators with larger diameter require a larger number of blades in order to keep the distance between blades within the required limit.

Operation of Continuous Concentrator.—The operation of the continuous concentrator is simple and the ratio of concentration of the product can be regulated as desired.

Heating of Milk.—Similarly as in case of evaporation in vacuo, it is desirable, if not necessary, to heat the milk before it enters the concentrator. This not only increases the capacity of the machine, but it also prepares the albumin and casein in the milk for the superheating to which the milk is subjected in the concentrator. Any method of forewarming or preheating may be used for this purpose, but since the milk flows to and through the concentrator, in a continuous stream, it is preferable to also use a forewarmer of the continuous type. The milk should be heated to about 185 to 200° F. and the forewarming should be so arranged that the milk is exposed to this temperature for 5 to 10 minutes before it enters the concentrator.

Condensing.—The concentrator is flushed with hot water and steamed, the parts of the agitator are assembled and installed in their proper place, the cover is securely bolted over the opening in the front head and the machine is ready for operation. Before starting the agitator a small amount of milk is permitted to flow into the concentrator so as to prevent the blades from running over the dry heating surface, cutting the copper. Simultaneously with the starting of the agitator the steam is turned into the jacket and then the milk intake valve is opened.

The steam pressure on the jacket is kept uniform, preferably at 40 to 50 lbs. of steam. This machine evaporates the milk at atmospheric pressure. The temperature of the milk in the concentrator therefore, is practically the same as that of boiling water—212° F.—at the sea level and varies only with the altitude of the location. The ratio of concentration and the density of the finished product are regulated by the rate of inflow of fluid milk. The density is determined by the use of the Baumé hydrometer. With a constant rate of inflow and uniform steam pressure in the jacket the concentrator yields a condensed milk of uniform density.

No subsequent superheating of the concentrated milk is necessary. This product can be made of any consistency desired, regardless of concentration (within reasonable limits) by regulating the thickness of the milk film on the heating surface. The

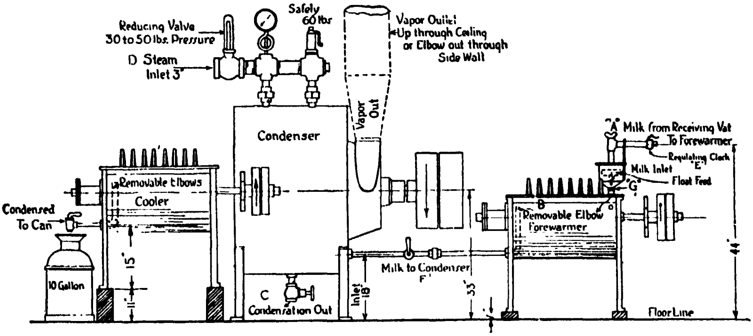

Fig. 90. Continuous concentrator unit for preheating, concentrating and cooling
Courtesy of Creamery Package Mfg. Co.

thickness of the milk film is controlled by adjustment of the condensed milk discharge with respect to its distance from the periphery of the drum.

Cooling the Condensed Milk.—This is most advantageously done by permitting the discharge of the concentrator to flow over or through a continuous-flow cooler. The concentrator unit is usually furnished with a disc-continuous cooler which has proven very serviceable for this purpose. However, most types of coolers used for the cooling of plain condensed milk and superheated milk are suitable to use for the cooling of concentrated milk. The cooled product is now ready to be packed into 10 gallon cans or other containers for the market.

Types of Concentrated Products that Permit of the Use of the Continuous Concentrator.—The continuous concentrator lends itself to the manufacture of all types of unsweetened condensed milk products, such as plain condensed milk, plain superheated condensed milk, evaporated milk, condensed butter milk, condensed whey, and pre-condensing of butter milk for drying.

This equipment and process is not so well adapted to the manufacture of sweetened condensed milk. It could be used for this purpose, however, by deferring the addition of the sugar until after condensing, in which case the sugar would have to be added in the form of a concentrated syrup (preferably containing about 60 to 65% sugar in hot water) before cooling.

PART IV

Condensed Milk Markets, Composition and Properties

CHAPTER XX

PREPARATION FOR MARKET

Stamping Package for Identification.—The importance of systematic marking of the consumer's package for future identification is obvious. It is necessary for the completeness and accuracy of the manufacturing records; it facilitates the proper rotation of stocks; it is indispensable for the successful tracing of the causes of defects in the case of returned goods and thereby makes possible and expedites the prevention of their recurrence.

Identification is desirable both of bulk packages and of tins. The simplest system of marking the package is to stamp upon it the batch number. Most factories, however, prefer the use of a code of letters or figures, or a combination of letters and figures. The code usually designates the factory, date of manufacture and number of batch of the respective day's run. The code has the advantage of withholding information from competitors.

The barrels are preferably stamped both on the head and on the side and the stamping is done by hand. The cans are usually stamped on the bottom, which is the end that carries the cap. Factories with small output generally use small interchangeable rubber letters and figures for stamping by hand. The stamping ink should contain a drier and be waterproof. In factories with large production the stamping is done by an automatic stamping device which is attached to the filling, sealing, or labeling machine. Instead of the stamping of the cans the labels may be perforated with the batch or code number.

Inspecting.—The sealed and stamped cans are placed, caps down, in wooden trays holding twenty-four medium-sized cans. All trays of one batch are stacked together. A card indicating number and date of batch and number of cans in the batch is attached to the stack and a copy of the same is filed in the office. The cans are placed with their caps down in order to detect "leakers" (cans with defective seals). Before labeling, the trays should be taken down, the cans turned over and examined for leaky seals. Unless the factory is behind in filling orders, the cans will have been in stock at least twenty-four hours or usually longer. In the case of sweetened condensed milk, if any seals are defective, a little condensed milk will have oozed out by that time.

In the case of evaporated milk (unsweetened, sterilized) all cans coming from the incubating room should be individually shaken by hand. All cans showing no signs of bulging, and the contents of which shake with the characteristic sound and behavior of a homogeneous liquid, pass inspection. If the ends of the cans are bulging or the contents do not respond to the shaking with the characteristic sound of normal milk, they are rejected, as the evaporated milk in them has either undergone gaseous or curdling fermentation, and is spoiled.

Labeling the Tins.—In the early days of the milk condensing industry, the labeling of the cans was done by hand, involving much time and considerable expense. Today, especially constructed labeling machines are almost exclusively used for this purpose. The efficiency and quality of work of these machines are such, that they have become a permanent fixture in practically every condensery selling canned goods. The labeling machines are adjustable to various sizes of cans and can be operated by hand, motor, or belt power.

Principle of Labeling Machines.—The cans are placed into a chute from which they roll into the machine by gravity. They are caught by two endless belts which draw them through the machine. They first pass over revolving metal discs that touch each can with a trace of "pick-up" cement. From here the can rolls over the label table which is loaded with a stack of labels, face-down. The touch of "pick-up" cement on the cans causes each can to pick up one label, which is automatically wrapped around the rolling can. An endless belt passing through a paste box applies a small strip of paste to the lap of the label and a curling rod stretches the label taut and gives its lap an inward curl, making it conform to the shape of the can and ensuring a perfect seal. The label table is equipped with an automatic feeding arrangement which pushes the stack of labels up as fast as the labels are being used.

The modern labeling machines are equipped with diverse mechanical refinements that facilitate their continuous operation, and improve the appearance of the labeled tins, such as automatic glue feed, non-stop label pack feeder, mechanical inspector which removes and returns through the machine cans that escape without having been labeled.

Wrinkles and Rust Spots on Labels.—In the latest models of labeling machines no paste touches the cans proper. The "pick-up" cement used on the cans, is moisture-proof and is applied hot. This is a great advantage from the standpoint of ensuring freedom from rust spots on labels. The cement, being applied hot, dries instantly and having no corrosive action on the can, is a reliable safeguard against wrinkles and rust spots, which are so prone to appear where paste is used exclusively, and which mar the attractiveness and neatness of the package. The labeled cans which now leave the machine over a chute slanting from it, can be cased immediately without risk. The use of tables and fans to dry the labels, often found necessary in the case of mechanically applied paste, is made superfluous, and time, labor and space are saved.

Capacity of Labeling Machines.—In the latest improved types of labeling machines the capacity has been greatly increased over that of the older models. One properly operated hand-driven machine will now label on an average from 40,000 to 50,000 cans and a power-driven machine will average from 60,000 to 70,000 cans per ten-hour day.

Packing in Cases.—The labeled cans are packed in cases holding from six to ninety-six cans, according to the size of the cans. (One case holds six 1-gallon cans; forty-eight 14-, 15-, 16- and 20-ounce cans; or seventy-two to ninety-six 8-ounce cans.)

In the case of nailed wooden boxes the sides, bottom and top of the cases should be of material about three-eighths of an inch to one-half inch thick, the ends three-fourths of an inch to seven-eighths of an inch thick. The cases are usually bought in the "knock-down" shape and are made up in the factory. Six-penny cement-coated wire nails are most suitable for this purpose. The cases are most economically nailed by the use of nailing machines, which nail one entire side or one side and one end simultaneously. The cans are usually placed into the cases direct from the labeling machine. In some factories, packing machines, which pack twenty-four medium-size cans in one operation, are used. Formerly condensed milk cans were packed exclusively in nailed wooden cases. Within the last few years the use of collapsible wire-bound boxes and paste-board and fibre boxes has been adopted in many condenseries. These boxes are proving very serviceable and make possible a considerable saving in the cost of the package.

Mechanical can casers, operating with the labeling machine, are now available and are used to advantage in many condenseries. The can caser receives the labeled cans from the labeling machines, stacks them into layers, places the layers of cans into the case and automatically pushes off the filled case, while a new layer of cans is pushed forward. It is obvious that the mechanical can caser makes the work of packing the cans easier and accelerates its speed; its use saves one person. It eliminates the possibility of deranging of labels, as frequently occurs with hand-casing through taking hold of freshly-pasted laps as the cans are removed from the "rundown" of the labeler. There is no smearing of the labels from dirty fingers, thus preserving the neat appearance of the label.

Marking the Cases.—One end of each case is stenciled with the number of the batch; over the other end is pasted a case label, representing, enlarged, the brand of the label on the cans within. In the place of the case label, the respective brand may be printed on or burnt into the wood. The burnt stenciling is usually done by the manufacturer of the shooks. One side of each case is usually marked "Condensed Milk" or "Evaporated Milk," as the case may be; the other "Keep in cool, dry place." If sweetened condensed milk is exposed to excessive heat for a considerable length of time, as is often the case in storehouses or in the hold of steamers, where the cases may be stowed against the boiler room, it becomes brown, thickens rapidly and develops a stale flavor. Evaporated milk also darkens when exposed to heat and depreciates in flavor. It should, therefore, be kept in a cool place. The humidity of the storage room has no effect on the condensed milk proper, the cans being hermetically sealed. Prolonged exposure to dampness, however, will dampen and wrinkle the labels, rust the cans and invite the appearance of rust and mold spots.

Packing Condensed Milk for Export.—In the case of condensed milk bought by the United States Government, the cans are dipped in a solution of shellac before they are labeled, or the tin plate or empty cans are bought by the manufacturer already lacquered. Cans for export trade and in many instances for the home market, are wrapped into heavy, soft paper, bearing on the outside a copy of the respective brand. This wrapping paper takes up the space between the cans and prevents the cans from being damaged on their long journey and by rough usage. This wrapping is usually done by hand or by the labeler. The cases are reinforced with a band of strap iron around each end.

STORAGE

The purpose of storing condensed milk is similar to that of storing butter and other produce. It is to hold the surplus product from the time of large supply and low prices to the time of shortage and high prices.

Temperature of Storage.—The optimum storage temperature is determined to some extent by the type and package of the condensed milk. Generally speaking, however, low storage temperatures (45 to 32° F.) are preferable to higher temperatures. This is especially true where prolonged storage is contemplated.

Plain condensed milk, which is not sterile and contains no cane sugar to preserve it, is highly perishable. It is usually intended for quick consumption. If it must be stored at all it should be held at temperatures only slightly above the freezing point of water. Even at these low temperatures it is inadvisable to hold it longer than one to two weeks. At high temperatures rapid souring is unavoidable.

Evaporated milk, if properly made, is sterile. Bacteriologically it will keep indefinitely provided that the tins are and remain air-tight. It is subject, however, to certain physical and chemical changes which are hastened and intensified at the higher storage temperatures. The more important of these changes are:

1. Increase in acidity.

2. Attack of metal of container leading to the development of metallic flavor.
3. Loss of body and of viscosity.
4. Darkening of color.
5. Precipitation and deposit of sediment of calcium citrate crystals.

All of the above defects will tend to develop in evaporated milk held at room temperature or above for a prolonged period of time (longer than about two months). These objectionable changes are almost completely avoided at storage temperatures below 45° F (but above freezing). It is advisable, therefore, to use these lower storage temperatures for evaporated milk that is to be held in excess of two months. For short-held goods (not exceeding two months) storage at ordinary temperature causes no appreciable changes.

Sweetened condensed milk, though preserved by sucrose, also suffers marked deterioration in prolonged storage at high temperatures. The most objectionable changes are the following:

1. Increase in acidity.
2. Bacterial development.
3. Appearance of white and yellow buttons.
4. Progressive thickening.
5. Darkening of color.

The development of some of these defects in high-temperature storage may be materially minimized by the proper adjustment of the manufacturing process, but at best the danger is ever present. Here again, as in the case of evaporated milk, the storage defects may be practically completely avoided by holding the storage temperature down to 45° F or below, unless the goods are held for a short period only (less than two months). Even in the case of short-held milk high temperatures jeopardize the quality, and a temperature of 60 to 70° F is preferable to higher temperatures.

In the case of bulk sweetened condensed milk intended for bakeries and confectioneries, storage for a limited time at room temperature may be preferable to cooler storage as the heavier body resulting from progressive thickening is preferred by the baker. Prolonged storage at these higher temperatures is not advisable, however, because of the unavoidable tendency of. the appearance of buttons and of discoloration.

Storage temperatures below the freezing point of water are undesirable. The evaporated milk freezes and while so doing it expands sufficiently to cause bulging of the ends of the tins. Although the bulge disappears upon thawing of the contents, there is danger of weakening the seams, inviting subsequent leaks. Furthermore, freezing changes the physical character of the milk. When remelted, the evaporated milk usually shows separation of whey and often the curd becomes permanently grainy. These defects may be corrected by subsequent shaking which, however, involves additional expense and lowers the viscosity.

Sweetened condensed milk does not suffer from freezing temperatures. Its freezing point is far below the freezing point of water because of its high sugar concentration. However, when sealed in tins with solderless seals, such as the friction cap or the burr cap, unexpected difficulties may arise. These seals are not air-tight. Excessively low storage temperatures cause the contents and the air in the can to contract sufficiently to draw in air through the imperfect seal; the viscous milk seals the microscopic openings on the inside of the tin. When the cans are taken out of cold storage and warm up, the contents and the air expand but the excess air finds no exit. The resulting pressure causes the tins to bulge and in this condition the package gives the erroneous impression of spoiled goods, which may induce their rejection on the market.

Semi-solid buttermilk and concentrated sour milk, on account of their high acid concentration, require no cold storage; even summer heat causes no spoilage unless the goods are exposed to the air. These products likewise are not affected by temperatures below the freezing point of water.

TRANSPORTATION

Plain condensed bulk milk and concentrated milk, if shipped considerable distances during warm weather should be placed in refrigerator cars or packed in insulated cans.

Evaporated milk and sweetened condensed milk in hermetically sealed cans, and the latter also in barrels, can safely be shipped in ordinary box cars. The cases weigh from fifty to sixty-five pounds, and the barrels from three hundred to seven hundred pounds. Care should be taken that the cars used for this purpose are clean and did not previously carry goods with strong and obnoxious odors, such as fertilizers, as these odors are prone to follow the condensed milk to its destination. Strong box cars, in good repair only, should be used. Even at best, the cases and cans suffer more or less damage in transportation. Cars with leaky roofs should be condemned. If shipped on steamboats, it should be specified to stow the cases away from the boiler room and from steam pipes.

CHAPTER XXI

CONDENSED MILK MARKETS

The consumption of canned milk in the United States has been growing rapidly within recent years. This is especially true of evaporated milk which appears to be given marked preference over sweetened condensed milk by the American consumer. On the continents of Europe and Asia the consuming public continues to favor sweetened condensed milk. The total annual consumption of evaporated milk in the United States has increased from 774,575,000 pounds in 1920 to 1,563,714,000 pounds in 1932; the consumption of sweetened condensed milk increased from 56,938,000 pounds in 1920 to 186,712,000 pounds in 1922 and then decreased until in 1932 it amounted to 59,759,000 pounds. In addition to these direct outlets for direct consumption, diverse food industries utilized in 1931 approximately 300,000,000 pounds of plain condensed milk and nearly 200,000,000 pounds of sweetened condensed milk in barrels, while 64,000,000 pounds of condensed buttermilk and 27,000,000 pounds of concentrated sour skimmilk were absorbed for animal and poultry feeding purposes.

Large volumes of canned condensed milk, both sweetened and unsweetened also supply localities, territories and countries where the dairy industry is as yet in its infancy, or where geographic and climatic conditions bar the profitable husbandry of the dairy cow. Thus, we find some of the most promising markets for condensed milk in the tropics and in the arctic regions, in the army and navy, on ocean liners and in mining and lumber camps. In these markets the concentrated product has, in many instances, become as great a necessity as fresh milk is to the consumer within the dairy belt of the temperate zone.

Market Price of Condensed Milk.—The market price of condensed milk is governed by such factors as demand and supply in domestic and export markets, condition of international rate of exchange, duty on imports, the price situation of market milk, butter and cheese, and the brand, whether known brand (premium brand) or miscellaneous brands.

Within the span of the past 20 years condensed milk prices in this country have fluctuated widely, partly on account of removal and later reinstatement of the tariff on imported goods and partly because of the extraordinary upheaval of monetary, economic, industrial and market conditions during and following the world war.

During the above period sweetened condensed milk sold at prices ranging anywhere from $2.50 to $9.25 per case of 48—14 ounce cans; and evaporated milk prices ranged from $1.90 to $6.50 per case of 48—16 ounce cans.

In 1913, the United States, by Act of Congress, removed the import tariff, placing condensed milk on the free list. This Act became effective in the fall of the same year. Its immediate effect was a rapid increase in the importation of European condensed milk, which was offered for sale at relatively low prices, decreased the sale of domestic goods and caused the holdings of condensed milk to accumulate in large quantities. Condensed milk prices depreciated rapidly throughout 1914 and reached the bottom in the fall of that year when financial limitations compelled many concerns to move their goods at any price. At that time the bottom prices of condensed milk were approximately as follows:

Sweetened condensed milk per case......	$2.50
Evaporated milk per case...............	1.90

The losses suffered by this slump in the condensed milk market, caused by the influx of cheap foreign goods in the absence of a protective tariff, were large and caused bankruptcy of several of the financially limited concerns. The outlook for the future of the industry seemed very uninviting at best, but the situation was saved and market conditions reversed by the urgent food requirements of the Allied nations in the European war, and after the entrance of the United States into the war, by large orders for the American army and navy.

The extraordinary and very urgent demand for condensed milk by the U. S. Government and by its allies during the war and the enormous demand for exports to Europe after the armistice, boosted the prices of this product to a level not attained since the Civil War. While Government regulations tended to hold price advances within reasonable bounds and while lack of shipping facilities and other factors caused temporary fluctuations downward, the price advance in general continued until the spring of 1919, and reached the following maximum figures per case:

Sweetened condensed milk per case......	$9.25
Evaporated milk per case...............	6.50

From 1920 on prices began to decline rapidly as the result of a speedy decrease in the export demand and the simultaneous continuance of the tremendous volume of war-time production. This situation caused a rapid accumulation of stocks in this country. During the war period the industry had grown with leaps and bounds. In 1919 this country exported more condensed milk than was represented by the entire output of 1914. With the export market suddenly shut off (in 1920) the greatly increased production caused the accumulation of a large surplus which the domestic market was not prepared to absorb. The situation was further aggravated by the arrival of some imports attracted by the favorable rate of exchange and the absence of an import tariff.

This combination of conditions had a depressing effect on domestic market prices. With the gradual readjustment of the rate of exchange and of the general economic conditions and the reinstatement of the tariff on imported goods, encouraging exports and discouraging imports, together with a marked improvement in business conditions domestically, this surplus was gradually absorbed so that by 1924 market prices returned to normal. In 1925, summer, sweetened condensed milk sold at from $5.75 to $6.00 per case of 48—14 ounce cans, and evaporated milk at from $3.75 to $4.40 per case of 48—16 ounce cans.

The rise in prices continued through the years of the unprecedented business expansion and in 1929 premium brands of sweetened condensed milk were quoted at $6.30 to $6.35 per case of 48—14 oz. cans, and of evaporated milk at $4.70 per case of 48—16 oz. cans. The business paralysis that followed the business boom reversed the price trend and by the end of 1933 prices had dropped to $4.85 per case of sweetened condensed milk and $2.70 per case of evaporated milk. The above prices refer to nationally advertised premium brands. Other brands sold for from 20 to 40 cents less.

Similar price fluctuations occurred also in the case of bulk goods which toward the close of the year 1933 sold as follows:

Sweetened condensed whole milk (in barrels) (U.S. Standard)	6¾-7¢ c.w.
Sweetened condensed skimmilk (in barrels) (28% M. S.)	4½-4¾¢ c.w.
Plain condensed whole milk (10% fat)	$7.50 per 40 qt. can
Plain condensed whole milk (8.5% fat)	$6.50 per 40 qt. can
Plain condensed skimmilk	$2.50 to $3. per 40 qt. can

The most important markets for bulk sweetened condensed milk are bakeries, confectioneries, candy factories, while the large bulk of plain condensed milk goes to ice cream factories. Generally speaking, the marketing of plain condensed milk yields the larger margin of profit but the demand, depending on the ice cream business, is seasonal and not constant throughout the year. The margin of profit on sweetened condensed milk is usually more limited but the demand is sufficiently constant to offer a dependable outlet for surplus milk when the ice cream season is over and the demand for plain condensed milk is declining.

INTERNATIONAL TRADE IN CONDENSED AND EVAPORATED MILK

The principal countries exporting and importing concentrated milks and their annual exports and imports are given in Tables 23, 24 and 25, respectively.

Exports.—The fundamental conditions favoring exports of concentrated milks are: dairy development sufficient to provide a plentiful supply of fluid milk, a balance of feed, land and labor cost that makes possible relatively low cost of production, and close proximity to favorable export markets. This combination of factors appears to apply particularly to such countries as the Netherlands, United States, Switzerland, Denmark and Canada. As shown in Table 23, these countries are, in fact, the leading exporting countries.

Prior to the World War exports from the United States were small, as shown in Table 25, supplying largely only countries of the North American continent and Panama; limited quantities were exported also to Oceania and Asia and only small quantities to South America, Africa and Europe. The great bulk of concentrated milk that entered international commerce consisted of exports from European countries.

The World War completely changed the movement of milk in international trade. The killing of cattle for meat and the high cost of cattle feed in Europe brought about a great reduction in milk production and in the volume of milk available to European condenseries. The shortage of sugar and tin plate further augmented the difficulty, increasing the cost of manufacture and decreasing the output of European factories. The growing food shortage in the Allied countries and their need of condensed milk for armies, navies and civilian population called for large imports on the part of Europe. In addition, the war deprived noncombatant countries in South America, Asia and Africa of their usual imports from Europe and opened up vast markets for this commodity in those countries.

Table 23.—Exports of Condensed and Evaporated Milk.*
Countries Importing 10,000,000 Pounds or More

Country	Average 1923-27	1927	1928	1929	1930	1931
	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds
Netherlands	265,563	324,800	354,572	378,059	393,151	415,432
United States	153,177	103,028	115,551	110,185	90,459	75,085
Switzerland	67,356	81,234	82,252	78,475	72,660	63,432
Denmark	61,715	55,304	52,597	54,934	51,916	49,233
Canada	37,776	33,680	27,118	26,746	20,471	14,458
Australia**	19,356	15,517	18,647	21,837	13,242	9,988
Norway	17,482	16,698	18,747	15,534	13,447	11,170
United Kingdom	16,327	27,771	25,046	27,732	22,441	14,904
Italy	11,530	8,905	7,093	4,629	5,141	6,374
France	6,853	9,454	12,483	10,204	13,127	14,074
Irish Free State	6,186	6,302	10,747	10,503	9,720	6,565

*Assembled from T. R. Pirtle's Handbook of Dairy Statistics, 1933.
**Four year average.

These conditions shifted the exporting of condensed milk to the United States, Canada, Australia and New Zealand and caused the export trade of these countries to expand enormously. The large exports continued to increase even after the armistice, partly due to the exhaustion of the European countries, and their inability to return immediately to productive enterprises, and partly because of the large amount of credit extended by the American government to Allied governments for the purchase of American products, and the relief activities on the part of the United States in Belgium, Russia and the Balkans.

Toward the close of the year 1919 conditions began to change and from 1920 on exports to Europe declined rapidly. The principal factors involved in this change had to do with the fact that European countries accumulated large stocks of concentrated milks in 1919 and 1920 and it required several years to consume this surplus. The increasingly unfavorable rate of exchange of foreign moneys discouraged importation by European countries. The growing revival of dairy and condensed milk production in Europe and the raising of tariffs "over there" further hastened the decline of the demand of American milk. Exports from the United States continued to decrease until 1926. During the years 1926-29 they remained fairly stationary, but since 1929 the prolonged world depression with its paralyz-

Table 24.—Imports of Condensed and Evaporated Milk.*
Countries Importing 10,000,000 Pounds or More

Country	Average 1923-27	1927	1928	1929	1930	1931
	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds	1000 Pounds
United Kingdom.....	260,302	283,789	301,978	296,501	291,010	380,979
Cuba...............	46,016	50,586	44,340	46,492	38,767	16,433
Dutch East Indies...	22,045	26,149	30,875	34,990	33,416	28,695
Philippine Islands....	21,479	25,974	26,524	29,875	29,077	35,253
Germany[1]...........	17,893	13,434	13,290	8,264	4,351	1,966
France..............	17,502	11,299	12,271	12,975	14,965	17,610
British India........	15,030	24,933	26,354	27,436	27,261	21,531
Japan..............	10,809	9,510	8,411	8,865	8,396	7,679
Union of South Africa	10,620	11,330	12,020	12,132	4,310	2,510
China..............	10,422	11,095	14,643	13,285	11,353	10,026

*Assembled from T. R. Pirtle's Handbook of Dairy Statistics, 1933.

[1] Includes some powdered milk.

ing effect on international trade has brought about a further continued decline in exports of American concentrated milks.

Imports.—The fundamental essentials that make a country a large importer of concentrated milk are large population with milk-minded food habits combined with sparse cow population and limited production of fluid milk, in the presence of no tariff or only moderate rate of import duty on concentrated milk. As shown in Table 24 the leading importing countries to which the above combination of factors applies are: the United Kingdom, Cuba, Dutch West Indies and Philippine Islands, in the order named. Other countries with considerable though lesser capacity as importers of concentrated milks are, Germany, France, British India, Japan. Union of South Africa and China.

Imports of concentrated milks by the United States never assumed large proportions as shown in Table 25. From 1909 to 1913 the imports were negligible. During that period America had an import duty of 2 cents per pound on all foreign condensed milks. In the fall of 1913 condensed milks were placed on the free list. This caused an immediate influx of European condensed milks into this country, particularly from Switzerland, Denmark, Holland, Sweden, Norway, Germany and Eng-

Table 25.—U. S. Exports and Imports of Condensed Milk and Evaporated Milk for the Years 1911 to 1932, inclusive.*

Year	Exports Pounds	Imports Pounds	Year	Exports Pounds	Imports Pounds
1911	12,180,445	630,308	1922	187,497,000	5,294,000
1912	20,642,738	698,176	1923	194,246,000	6,105,000
1913	16,525,918	1,778,044	1924	206,014,000	6,003,000
1914	16,209,082	14,599,339	1925	173,547,000	8,033,000
1915	37,235,627	33,624,189	1926	135,864,000	1,430,000
1916	159,577,620	18,174,505	1927	103,028,000	2,623,000
1917	259,102,213	18,375,698	1928	115,551,000	2,610,000
1918	553,439,554	29,926,931	1929	110,186,000	2,634,000
1919	852,275,264	16,509,239	1930	90,459,000	1,612,000
1920	411,077,982	23,755,780	1931	75,085,000	1,245,000
1921	289,724,820	8,667,626	1932	50,807,000	1,188,000

*U. S. Dept. Commerce and Labor, Bur. Statistics for 1911-'24; U. S. Dept. Agriculture, Bur. Agr. Ec. Rept. F. S. 42, for 1925-'26; U. S. Dept. Commerce, Bur. Foreign & Dom. Commerce, 1927-'33.

land. At first the bulk of this influx consisted of sweetened condensed milk, but soon evaporated milk also arrived in increasingly large quantities. These importations caused an unprecedented demoralization of the domestic market of concentrated milks. The American imports reached their maximum in 1915, when the growing food shortage in the Allied countries began to counteract the westward movement of trade. In 1921 concentrated milks were again taken off the "free list" and the new American tariffs that became effective in 1921, 1922 and 1930, respectively, tended to cause a progressive decline of imports into the United States, so that by 1932 the total imports of concentrated milk were no larger than those in 1913. For tariff schedules on imports of concentrated milks into the United States see Table 62, Chapter XXXVIII.

CHAPTER XXII

MANUFACTURE OF SWEET, STERILIZED CREAM

The universal consumer demand for sweet table cream is an opportunity fully recognized by the dairy industry. However, as in the case of sweet milk, there are many regions where the fluid product is not readily available, if available at all, because of distance from source of supply of so perishable a product. The absence of fresh milk in such cases is readily compensated for by the availability of milk in concentrated form, such as evaporated milk, sweetened condensed milk, or milk powder.

In the case of sweet cream the problem is not so much one of excessive bulkiness. In fact, cream of average fat content usually contains as much total milk solids and as little water as evaporated milk. The problem with cream is chiefly one of such treatment in manufacture as to render it dependably sterile without making it permanently lumpy, or giving it a dark color or objectionable cooked flavor, and to prevent fat separation in storage and churning in transportation. It is a problem of rendering it sufficiently stable to insure its arrival on the market in its natural, unchanged condition, regardless of climatic conditions to which it may be exposed.

The successful accomplishment of producing a sweet cream that is sufficiently stable to withstand the rigors of prolonged storage, and of transportation to distant markets, and of exposure to a wide range of temperature conditions, is of significant economic importance to the industry, promising new and attractive channels of disposition of the product of the dairy cow. Such a product has been developed in the form of sweet, sterilized cream available in hermetically sealed tins or bottles. This is a comparatively new product; its usefulness and the potential demand for it are so obvious that its successful manufacture promises a ready and rapidly increasing market.

Fundamental Problems Involved.—The successful manufacture of sweet, sterilized cream envolves mastery of those factors and conditions that control the stability of the cream toward heat necessary for dependable sterilization, and the prevention of objectionable separation of its milk fat in subsequent storage. These problems have the same scientific background and their solution is controlled by similar factors as apply to and have been discussed in detail under "Evaporated Milk".

In the case of evaporated milk these problems may be considered solved as far as commercial manufacture is concerned. With sweet, sterilized cream the difficulties dealing with heat coagulation and fat separation are somewhat augmented and their solution calls for attention to additional details because of the much higher fat content and the much lower solids-not-fat content of this new product.

A definite process of manufacture of sweet, sterilized cream, covered by U. S. Patent, was devised by Webb[102, 103, 104] who made an extensive experimental study of the factors affecting the heat coagulation, viscosity, fat separation, color and keeping quality of sweet cream. This process is a modification of the methods employed in the manufacture of evaporated milk. Its development was greatly assisted by the results of diverse other investigations on related factors, such as the factors affecting fat clumping and the viscosity of milk, cream and ice cream mixes as studied by Doan[105, 106, 107], Troy and Sharp[108], Tracy and Ruehe[109], Reid and Skinner[110], Hening and Dahlberg[111], Dahlberg and Marquardt[112], Hening[113], Babcock[114]; the effect of homogenizing on feathering and heat stability, by Burgwald[115] and Doan[116]; the effect of two-stage and double homogenization on fat clumping, viscosity and heat stability, by Martin and Dahle[117], Tracy and Ruehe[109], Doan and Minster[118]; the effect of forwarming temperatures and homogenization, by Webb and Holm[96]; factors affecting whipping cream, by Babcock[119]; the color of evaporated milk, by Webb and Holm[120].

Process of Manufacture Recommended.—According to our present knowledge as based on available data of experimental results with sweet, sterilized cream a satisfactory product may be obtained by observing the following succession of steps and of relationships of factors in the process of manufacture:

1. Use fresh, sweet cream only with a titratable acidity of less than .15 per cent calculated as lactic acid.
2. Standardize this cream to 20% fat.
3. Preheat at 176° F without holding.

4. Double homogenize at 176° F, either by the use of the two-stage valve or by re-homogenization, using 2500 to 3000 pounds pressure for the first stage and 500 pounds pressure for the second stage or for re-homogenizing. For re-homogenizing bring the temperature of the cream back to 176° F.

5. Cool to 60° F. immediately after homogenizing, preferably by running the cream over a brine cooled surface cooler.

6. Pack into air-tight containers, such as plain tins, lacquered tins, or glass bottles of the soda water type.

7. Sterilize in batch sterilizer, same as is used for evaporated milk, using 15 minutes for coming up and for cooling. Hold at a sterilizing temperature of 118° C. (244.4° F.) for from 12 to 15 minutes, depending on the size of the container.

The results of extensive work by Webb show that sweet, sterilized cream made in accordance with the above formula is free from noticeable darkening in color or change in viscosity due to manufacture or storage; that its cooked flavor is so slight that it is not objectionable; that it will keep indefinitely without serious objectionable change in flavor, although upon prolonged storage there is a tendency for the appearance of a slight "milk powder" or "old cream flavor"; and that, while a considerable period of storage diminishes the uniformity of fat dispersion somewhat, the cream plug is of loose texture and readily disintegrates and emulsifies in the contents upon slight shaking.

FACTORS THAT INFLUENCE THE MARKETABLE PROPERTIES OF SWEET, STERILIZED CREAM

Quality and Acidity of Cream.—Age and acidity lower the heat stability of milk and cream. In the preparation of sterilized sweet cream the high fat content and the homogenization pressure used augment heat coagulation difficulties. These two disturbing factors cannot be eliminated, since a relatively high fat content is the very essence of a product marketed as cream, and since the successful prevention of objectionable fat separation makes the use of homogenization at relatively high pressures unavoidable.

In order to guard as much as possible against sterilizing difficulties, therefore, it is important and essential that the raw material, the fluid sweet cream, be fresh and of high quality. Absolute freshness of cream is indispensable in the successful manufacture of sweet, sterilized cream. The titratable acidity of the cream should be below .15%.

Butterfat Content.—A good quality of cream containing 20 per cent butterfat, when preheated to the proper temperature (176° F.) before homogenizing, permits of efficient sterilization without coagulation. Unfortunately the finished product made from 20 per cent cream is not a satisfactory whipping cream. It does not whip easily and the whip is of small volume. This is due to the combined effect of low fat content and high homogenizing pressure made necessary to prevent fat separation in storage.

An increase in fat content lowers the heat stability of the homogenized cream and increases the tendency toward fat separation. A higher per cent fat sweet, sterilized cream can be made, however, and the whipping properties improved. Webb[103] suggests as optimum conditions for the preparation of a sterile whipping cream, a 30 per cent cream, preheated to 176° F., homogenized at 2,500 pounds pressure and sterilized at 244.4° F. (118° C.) for 12 minutes. His later work[104] that shows the advantages of two-stage or double homogenization suggests that two-stage or double homogenization at 2,500 to 3,000 and 500 pounds pressure, respectively, would be preferable in the case of the 30 per cent whipping cream. No experimental results are available, however, to substantiate this assumption.

The sweet, sterilized cream made by the above formula for 30 per cent cream whipped well at 50° F., but the increase in volume was small. The finished product, however, showed noticeable fat separation and an old cream flavor after one year of storage, although it retained its whipping property.

Preheating Temperature.—Troublesome heat coagulation encountered in the sterilization of homogenized cream is most dependably eliminated by preheating the cream before homogenization to 176° F. without holding.

The work of Webb and Holm[96] shows that, at every pressure of homogenization and for any per cent of fat up to 30 per cent, the maximum heat stability was attained by preheating to 176° F., excepting batches of low fat content and homogenized at low pressures, under which conditions preheating to 194° F. increased the heat stability.

One hundred and forty degrees F., which is considered the lowest practical temperature for homogenization, was found to produce the minimum heat stability of all creams, except those of very low butterfat content for which the minimum heat stability curve sometimes reached its lowest point at 158° F.

The practice of preheating by the recirculation method, as described under "Forewarming" in Chapter XII on "Evaporated Milk," might further improve the stabilizing effect of preheating the cream. In cases of persistent sterilizing difficulties the addition of a stabilizer before homogenization might prove helpful.

Homogenization.—The purpose of homogenizing the cream is to prevent fat separation after manufacture. Generally speaking, as the pressure of homogenization increases the tendency toward fat separation diminishes. It has been shown by Webb,[104] however, that single-stage homogenization at a pressure as high as 4,000 pounds does not entirely prevent fat separation in sterilized sweet cream upon prolonged storage.

The amount of pressure suitable to use is limited by the effect of homogenization on the heat coagulation point of the cream. Homogenization increases the viscosity and lowers the heat stability. This effect grows in intensity as the homogenizing pressure increases.

The causes of these phenomena have not as yet been established sufficiently by scientifically proven facts to justify their detailed discussion here. It is well known that homogenization decreases the size and increases the number of the fat globules. Recent observations have further revealed that these changes are accompanied by an increase in the number and density of the fat clumps. It is believed that the increased viscosity and diminished heat stability may be associated in some way with this fat clumping brought about by homogenization.

Hening,[113] who experimented with ice cream mixes, observed that a very considerable reduction in the size of the fat clusters is made possible in a mix homogenized at 2,000 pounds pressure by rehomogenizing four times at 200 pounds pressure. Webb[104] found that rehomogenization at a lower pressure, or the use of the two-stage valve will decrease the viscosity of cream.

These results and the observations of other workers suggest that this decrease in viscosity may be associated with less fat clumping and greater heat stability.

As the result of further study Webb recommends double or two-stage homogenization of cream at 2,500 to 3,000 pounds and at 500 pounds pressure, respectively. The advantage of this method lies in retaining the relatively high homogenization pressure that is necessary to prevent objectionable fat separation and in improving the heat stability in the sterilizer sufficiently to assist in securing a smooth product. There is a temperature drop of the cream during homogenization of about 10 to 20° F. For proper rehomogenization the cream should be brought back to the original preheating temperature of 176° F.

In order to insure minimum tendency of fat separation in the finished product, the fat globules in the cream after homogenizing should average not more than 1 micron in diameter. The microscopic field should show uniformity of size and absence of larger globules.

Filling and Sealing.—After homogenization the cream is cooled promptly to about 60° F. This is preferably done by discharging the homogenizer over a brine-cooled surface cooler or by pumping the cream through an internal tube cooler.

The cream is now ready to be filled into the consumer's package. Webb studied the suitableness of different containers such as plain tins, lacquered tins, and glass bottles similar to soda water or grape juice bottles. The cream was stored in these containers at room temperature from three to four and a half years.

While all of these containers proved satisfactory from the standpoint of their effects on the flavor of the cream, some difference was noted in their effect on the color. The cream in the glass containers had darkened in a manner similar to the change noted during prolonged heating of the product. He attributes this change in color to a change in the three color attributes, namely, hue, brilliance, and chroma. The cream samples stored in tins had a greenish tinge which was attributed to an increase in chroma alone. Webb further reports that the glass containers sealed with caps lined with parchment or special cardboard passed through the sterilizer satisfactorily and withstood sterilization without breakage or loss of tops. Caps lined with composition cardboard, however, blackened the top layer of the cream with which they came in contact.

Sterilization.—The same equipment, the batch sterilizer with revolving cage, and similar manipulation in sterilizing and cooling, as described under "Manufacture of Evaporated Milk," are applicable for the sterilization of sweet, sterilized cream.

The sterilizing temperature found most satisfactory is 118° C. (244° F.) for 12 to 14 minutes; using 15 minutes for bringing the temperature up and for cooling to room temperature after sterilization. This time schedule applies to one-half pint containers. For larger unit packages somewhat more time must be allowed for raising the temperature and for cooling.

It is probable that a more nearly complete absence of fat separation in subsequent storage might be accomplished without robbing the finished product of its desired smoothness, by stopping the reel intermittently during the stepping-up period. However, this practice would tend to darken the color more and to impart a more pronounced cooked flavor, defects which might prove objectionable from the market point of view.

CHAPTER XXIII

CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF CONDENSED MILK

It is not the purpose of this volume to present a detailed discussion of the chemistry of milk as such. Information of such general nature may be found in other treatises. This chapter is devoted to an endeavor to deal with those phases of the composition and properties of milk as are known to bear a direct relation to the composition, properties and behavior of the concentrated product and to the solution of some of the more important problems involved in its manufacture.

Table 26.—COMPOSITION OF COW'S MILK

Average, Maximum and Minimum Composition of Cow's Milk

Constituents of Milk	Maximum	Minimum	Average Composition by Different Investigators				
			Farrington & Woll*	Van Slyke** 5552 analyses	Eckles†	Babcock††	Fleischmann‡
	%	%	%	%	%	%	%
Water	90.0	82.0	87.4	87.1	87.1	87.17	87.75
Fat	7.8	2.3	3.7	3.9	3.9	3.69	3.40
Casein	4.5	1.5	3.2	2.5	3.4	3.02	2.80
Albumin		.5		.7		.53	.70
Milk sugar	6.0	3.5	5.0	5.1	4.75	4.88	4.60
Ash	.9	.6	.7	.7	.75	.71	.75
Total solids			12.6	12.9	12.80	12.83	12.25
Solids, not fat			8.9	9.0	8.90	9.14	8.85

Specific gravity at 60° F. 1.029—1.034; average 1.032.
Specific heat at 61-62.6° F. .9406—.9523 (Chanoz and Vaillant).
At 57-61° F. .9457, at 81° F .9351 (Fleischmann‡).
Freezing point—.54 to —.57° C. Average —.555° C. (31° F.) (Grimmer‡‡).

*Farrington and Woll, Testing Milk and Its Products, 1916.
**Van Slyke, Modern Methods of Testing Milk and Its Products, 1916.
†Eckles, Dairy Cattle and Milk Production, 1923.
††Babcock, Wing Milk and Its Products, 1909.
‡Fleischmann, Das Buch der Milchwirtschaft, 1901.
‡‡Grimmer, Chemie und Physiologie der Milch, 1910.

Condensed Milk contains the same ingredients as the uncondensed milk from which it is made, and the individual constituents of the dry matter have the same percentage relation to each other as in the original fluid milk. This is true in all cases where no attempt is made at standardization of the ratio of fat to solids not fat. In the case of sweetened condensed milk the finished product contains added sucrose, or dextrose, or part sucrose and part dextrose. The percentage of total milk solids in the condensed milk obviously depends on the ratio of concentration.

In condensed milk not standardized as to fat and milk solids the ratio of fat to solids not fat may, and usually does, vary considerably. In mixed herd milk, such as is received at the condensery, these variations are largely due to breed and period of lactation, and to a limited extent to feed. They are confined largely, therefore, to differences between localities and between seasons.

Table 27.—Showing Ratio of Solids Not Fat to Fat in Average Milk of Different Breeds

Breed	Total Solids Per Cent	Fat Per Cent	Solids not Fat Per Cent	Ratio of Solids not Fat to Fat
Holstein	12.29	3.45	8.84	1 : .390
Brown Swiss	12.46	3.68	8.78	1 : .419
Ayrshire	12.98	3.85	9.13	1 : .420
Shorthorn	12.50	3.80	8.70	1 : .437
Devon	14.50	4.60	9.90	1 : .465
Jersey	14.90	5.14	9.76	1 : .527
Guernsey	14.20	4.98	9.22	1 : .540

The figures in the above table are taken from the work of Eckles.[121] They show marked variations in the per cent fat and in the percent total solids of milk from seven different breeds. They further indicate pronounced variations in the ratio of fat to solids not fat between the different breeds.

Thus, for instance, in average Holstein milk for every 100 pounds of solids not fat there are 39 pounds of fat, while in average Jersey milk for every 100 pounds of solids not fat there are 54 pounds of fat.

Table 28 shows the effect of the period of lactation in periods of four weeks each, on the per cent of fat and solids not fat in the average milk of 3 Jerseys, 3 Holsteins, 2 Ayrshires, and 3 Shorthorns, and the grand averages of all breeds. These figures are assembled from the work of Eckles and Shaw.[122]

Table 28.—Effect of Period of Lactation on Per Cent Fat and Per Cent Solids Not Fat in Milk of Jersey, Holsteins, Ayrshires and Shorthorns

Periods of 4 weeks each	Average Jerseys		Average Holsteins		Average Ayrshires		Average Shorthorns		Grand Total Average	
	Fat Per cent	Solids not fat. Per cent	Fat Per cent	Solids not fat. Per cent	Fat Per cent	Solids not fat Per cent	Fat Per cent	Solids not fat. Per cent	Fat Per cent	Solids not fat. Per cent
1st	5.20	8.93	3.14	8.17	3.94	9.20	4.08	9.35	4.00	8.74
2nd	4.91	8.68	2.87	7.77	3.68	8.71	3.88	9.03	3.85	8.41
3rd	5.02	8.91	2.78	8.06	3.60	8.76	3.71	8.91	3.79	8.50
4th	4.79	9.01	3.11	7.99	3.59	8.64	3.54	8.83	3.77	8.47
5th	4.88	8.72	3.11	8.16	3.70	8.68	3.56	9.03	3.82	8.53
6th	4.98	9.09	2.98	8.17	3.52	8.59	3.58	8.98	3.79	8.61
7th	4.93	9.09	3.03	8.28	3.63	8.38	3.69	9.23	3.83	8.78
8th	4.83	9.23	3.09	8.31	3.74	8.66	3.73	9.11	3.85	8.85
9th	4.84	9.08	3.05	8.46	3.71	8.82	4.19	8.88	3.97	8.81
10th	4.88	9.55	3.31	8.89	4.05	8.77	4.11	8.98	4.11	9.05
11th	5.23	9.56	3.30	9.44	4.92	8.63	....	....	4.22	9.24
12th	5.68	9.90	3.70	9.31	3.96	9.08	....	....	4.54	9.50
13th	5.48	10.62	4.48	9.30	4.18	9.09	....	....	4.66	9.57
14th	6.47	10.69	3.68	9.74	....	....	....	....	5.08	10.21

Slight variations reserved, the above table shows that the composition of the milk of each of the four breeds is affected in the same direction by the period of lactation. The grand averages for all breeds varied at different stages of the lactation from 3.77 to 5.08 per cent in fat content and from 8.41 to 10.21 per cent in solids not fat. For the first 4-week period, both the fat and solids not fat were appreciably above the minimum of the entire lactation. This was followed by a decline to the minimum during the second period. The fat remained at this minimum up to and including the 8th period, after which it steadily increased and was highest at the end of the lactation. The per cent solids not fat also reached its minimum during the second period. This was followed by a slight rise up to the ninth period and a more rapid rise from then on to the end of the lactation, when it was highest.

Tables 29 and 30 show analyses of different brands of sweetened condensed milk and evaporated milk, respectively. The wide variations in composition are characteristic of condensed milk made from milk that has not been standardized. European brands, as a rule, average somewhat higher in total solids and lower in water than American brands. This is especially true since the practice of standardizing for fat and solids not fat to conform with the U. S. Federal Standard has become

Table 29.—Chemical Analyses of Sweetened Condensed Milk of Eighteen Different Brands

Brand	Milk solids Per cent	Water Per cent	Fat Per cent	Proteids Per cent	Lactose Per cent	Ash Per cent	Sucrose Per cent
[1] "Silver Spoon" Hires' Condensed Milk Co.	31.90	28.68	8.40	9.12	12.56	1.91	40.38
[3] "Eagle" Borden's Condensed Milk Co.	31.08	25.99	8.72	8.15	12.35	1.86	42.93
[2] "Reindeer" Truro Condensed Milk Co.	31.23	27.33	9.56	8.32	13.42	1.80	41.44
[3] "Tip Top" Borden's Condensed Milk Co.	36.57	21.67	10.07	9.35	15.00	2.15	41.76
[3] "Challenge" Borden's Condensed Milk Co.	31.74	24.84	8.23	8.57	13.02	1.92	43.42
[3] "Sweet Clover" Mohawk Condensed Milk Co.	32.84	24.07	9.31	8.71	12.95	1.87	43.09
[3] "Arrow" Wisconsin Condensed Milk Co.	31.15	26.83	8.00	8.49	12.87	1.79	42.02
[3] "Blue Bell" American Condensed Milk Co.	35.56	26.50	9.31	9.50	14.80	1.95	37.94
[3] "Red Cross" Mohawk Condensed Milk Co.	34.78	27.14	11.07	7.92	14.03	1.76	38.56
[3] "Rose" Borden's Condensed Milk Co.	30.82	24.76	8.88	8.06	12.07	1.81	42.97
[3] "Magnolia" Borden's Condensed Milk Co.	31.98	26.32	8.64	7.84	13.50	2.00	42.00
[3] "Rustic" Michigan Condensed Milk Co.	30.00	27.63	8.60	7.07	12.60	1.73	41.00
[2] "Milk Maid" Anglo-Swiss Condensed Milk Co.	35.69	25.65	9.65	8.78	15.17	2.09	38.66
[3] "Jubilee" The Manitoba Dairy Co.	29.40	32.15	9.62	8.61	11.30	1.85	38.45
[2] "Export" Baldwin Condensed Milk Co.	32.24	26.69	11.50	8.50	12.35	1.80	41.07
[2] "Owl" Canada Milk Condensing Co.	31.61	30.84	10.61	8.47	12.40	1.81	37.55
[2] "Nestle" Henry Nestle	32.91	28.04	8.06	7.68	15.23	1.94	39.05
[3] "Upper Ten" U. S. Condensed Milk Co.	33.65	27.88	8.80	8.34	14.66	1.85	38.47

[1] Spitzer, Indiana Agricultural Experiment Station, 1910.

[2] McGill, Inland Rev. Dept., Ottawa, Bulletin No. 144, 1908.

[3] Cochran, Special Report of Analysis of Condensed Milks and Infants' Foods, Pennsylvania Dept. of Agriculture, 1905.

an established practice in this country. The Federal Standard was designed, not in the sense of representing the ideal, nor even the average composition, but to indicate the minimum limit of fat and total milk solids below which the product may no longer be considered and sold under the accepted trade name of "condensed milk."

The establishment and enforcement of the Federal Standard has been of material assistance in ridding the industry of fraudulent practices of skimming and undercondensing and in protecting the consumer who had no way of ascertaining the true food value of the product labeled condensed milk or evaporated milk.

Table 30.—Chemical Analyses of Twenty-four Different Brands of Evaporated Milk*

Brand	Solids	Water	Fat	Curd	Lactose	Ash	Total
	%	%	%	%	%	%	%
Gold Milk	29.25	70.75	9.42	8.44	9.75	1.54	99.90
Columbine	24.63	75.37	7.45	7.41	8.56	1.36	99.98
Every Day	26.20	73.80	8.07	7.54	9.10	1.47	100.15
Gold Milk	27.18	72.82	9.07	7.39	9.23	1.49	100.00
Star	29.04	70.90	8.35	7.86	10.37	1.62	99.16
Morning Glory	31.08	68.92	10.48	8.26	10.47	1.67	99.82
Carnation	23.81	76.19	8.05	6.49	7.55	1.24	99.49
Beauty	28.38	71.62	8.47	8.39	9.94	1.56	99.98
Van Camp's	27.89	72.11	8.69	7.52	9.66	1.54	99.52
Wilson's	25.23	74.77	8.70	6.53	8.68	1.37	100.05
Monarch	26.70	73.30	8.09	6.77	10.35	1.44	99.95
Diadem	24.96	75.04	8.16	7.06	7.92	1.33	99.51
Reindeer	26.66	73.34	8.08	6.88	10.21	1.45	99.96
Dundee	27.04	72.96	8.73	7.21	9.36	1.48	99.74
Sundry samples							
1	28.02	71.98	8.93	7.68	9.86	1.61	100.06
2	31.99	68.01	9.68	8.49	11.88	1.69	99.75
3	26.01	73.99	8.18	6.77	9.24	1.46	99.64
4	27.33	72.67	9.04	6.93	9.42	1.51	99.57
5	29.37	70.63	9.71	7.34	10.52	1.56	99.76
6	21.12	78.88	7.30	5.78	6.78	1.12	99.86
7	23.25	76.75	7.98	6.19	7.96	1.25	100.13
8	25.48	74.52	8.68	6.34	8.67	1.35	99.56
9	26.62	73.38	9.20	7.00	9.18	1.37	100.13

On the other hand, while these standards were intended to set the minimum limit of fat and solids for legal condensed milk, they have been adopted as the ideal standard of composition by the manufacturer. Under existing competitive conditions it has therefore become the established commercial practice to standardize the product to conform with the Federal Standard. But since the Federal Standard merely established the minimum limit, the practice of standardizing has had the unmistakable effect of lowering the per cent fat and solids not fat in the average American product.

---

*Hunziker and Spitzer, Indiana Agricultural Experiment Station, Bulletin No. 134, 1909.

For sweetened condensed milk the present Federal Standard prescribes not less than 8 per cent fat and 28 per cent total milk solids, and for evaporated milk not less than 7.8 per cent fat and 25.5 per cent total milk solids.

The above figures, in fact, are a very close approximation of the percentage composition of the great bulk of American condensed milk that reaches the market in tins under the names sweetened condensed milk and evaporated milk, respectively. Condensed milk sold in bulk, sweetened or unsweetened, is of variable composition. The percentage of fat and solids not fat varies with the requirements of the trade.

THE MILK FAT

Chemical Composition.—The fat of milk is a natural compound of several different fats which vary in their properties. The chief of these fats are the olein, palmitin, myristin, stearin, laurin, butyrin, caproin, caprylin, and caprin. Chemically these fats are made up of gylcerol (glycerin) as the base, and fatty acids, such as oleic, palmitic, myristic, stearic, lauric, butyric, caproic, caprylic, and capric acids. The exact nature of the molecular linkage of these several acids with the glycerin and the combination in which they are present in the fat molecule is still somewhat uncertain.

These glycerin-acid compounds are spoken of as the glycerides. They differ in their chemical and physical properties from one another, and the proportion in which each is present largely determines the properties or constants of the milk fat. The relative proportion in which the individual glycerides are present in the fat molecule varies with such factors as breed, period of lactation and feed of cows. Hence locality and season of the year have a considerable influence on the constants of the milk fat. Richmond[123] gives the following percentage composition of milk fat:

Table 31.—Composition of Milk Fat

Fats (glycerides)	Fats (glycerides)	Fatty acids of these glycerides	Glycerol of these glycerides
	%	%	%
Butyrin	3.85	3.43	1.17
Caproin	3.60	3.25	.86
Caprylin	.55	.51	.10
Caprin	1.90	1.77	.31
Laurin	7.40	6.94	1.07
Stearin	1.80	1.72	.19
Myristin	20.2	19.14	2.53
Palmitin	25.7	24.48	2.91
Olein	35.0	33.60	3.93
Total	100.0		

The acids of the milk fat are conveniently divided into two groups according to their solubility in water and their volatility. Thus the oleic, palmitic, myristic, stearic and lauric acids are insoluble in water and non-volatile. This group constitutes approximately 85 to 88 per cent of the total fatty acids in milk. The remaining fatty acids, i.e., the butyric, caproic, caprylic and capric acids are more or less completely soluble in water and are volatile, when detached from their glycerin base. This group constitutes approximately 12 to 15 per cent of the total fatty acids in milk.

It is not known that the chemical composition of the milk fat and variations in such composition affect or are affected by the processes of condensing and sterilizing. Analyses of the constants of milk fat in evaporated milk indicate that the fat in this product is entirely normal and contains the volatile fatty acids in a proportion similar to that in average fresh milk. Determinations of the fat constants in milk before and after condensing, such as would make possible direct comparisons, however, are lacking.

While experimental evidence of loss of fatty acids during the process of condensing is not available, experience in commercial manufacture shows unmistakably that under certain

Table 32.—The Composition of Milk Fats in Evaporated Milk*

Date of manufacture	Reichert Meissl number	Iodine number	Melting point of mixed fats	Melting point of insoluble fatty acids
August, 1908	28.48	33.64	33.3° C.	41.0° C.
November, 1908	29.52	33.60	33.4° C.	41.2° C.

*Hunziker and Spitzer, Ind. Agr. Expt. Sta., Bull. No. 134.

conditions the finished product falls short of the percentage of milk fat it should contain, as based on the per cent fat present in the standardized fluid milk times the ratio of concentration. Such fat shortages have been traced to excessive entrainment losses, such as occur as the result of faulty construction of the vacuum pan, or careless operation, or both. Analyses of the entrained milk revealed that such milk is much richer in fat than either the fluid milk or the finished product. In the absence of excessive entrainment losses discrepancies in the fat recovered in the condensed milk are negligible.

Under normal conditions of manufacture the milk fat in the finished product usually remains unchanged in character, it does not readily yield to age deterioration. It has been found in isolated instances, however, to suffer changes due to the action of biological, enzyme and oxidative agencies, leading to such flavor defects in sweetened condensed milk as rancidity and tallowiness. The causes and prevention of these defects are discussed in detail in Chapter XXV under "Rancid Flavor" and "Tallowy Flavor," respectively. The above fat deteriorations are confined to defective sweetened condensed milk. In evaporated milk the milk fat appears to remain normal and unchanged.

Physical Properties of Milk Fat.—The milk fat is present in milk in the form of minute droplets, the fat globules, of varying diameter. In freshly drawn milk the fat globules have been found to vary in diameter from .0001 mm. to .022 mm. The great majority, however, fall within the range of .001 mm. to .006 mm., averaging approximately .003 mm. Individuality and physical condition of the cow, and breed and period of lactation have a marked influence on both the range of size and the average size of the fat globules in milk.

The agitation to which the milk is subjected in the factory may, and usually does, modify the size of the fat globules. Violent agitation at high temperatures, such as pumping or prolonged boiling under vacuum tends toward subdivision and dispersion, causing a marked reduction in size and an increase in the number of small globules. The same treatment also results in some coalescence, and milk so agitated usually shows a limited number of unusually large units, while the number of medium size globules has diminished. Agitation at lower temperatures, below 150° F., promotes clumping, or aggregation of fat globules, in which the structure of the individual globules of the aggregate is preserved. The effect of agitation depends, aside from the temperature, also on the nature of the agitation and the fat content of the liquid. High fat content generally intensifies the effect.

The specific gravity of milk fat at 60° F. is approximately .93, while the specific gravity of skimmilk at the same temperature averages about 1.035. When milk is at rest, therefore, the fat, responding to the force of gravity, rises to the surface, unless the gravity force is counteracted by other forces.

Emulsion of Fat in Condensed Milk.—In the case of condensed milk the trade demands that the emulsion of fat-in-skimmilk be complete and permanent. Successful manufacture must prevent subsequent separation of the fat. From the standpoint of the effect of the force of gravity, the tendency of fat separation in the condensed product is magnified because of the greater density of the concentrated product. The specific gravity of condensed and evaporated milks obviously varies with the ratio of concentration and the relative proportions of fat, solids not fat and sucrose or dextrose they contain. Sweetened condensed milk has an average specific gravity of about 1.30, that of evaporated milk averages about 1.06-1.07.

In sweetened condensed milk the great viscosity of the product precludes the possibility of fat separation in spite of the wide difference in specific gravity between the milk fat and the syrupy concentrated skimmilk. Only in extremely abnormal cases is there danger of fat separation in this product. As explained in Chapter XXV, underconcentration or the use of forewarming temperatures so low as to greatly reduce the viscosity of the finished product, may cause the fat in sweetened condensed milk to rise to the surface upon storage, especially at relatively high storage temperatures. These conditions are abnormal, and separated sweetened condensed milk is an exceedingly rare defect.

But not so with evaporated milk. Prior to the use of the homogenizer the prevention of fat separation in this product was a real problem. The most successful way to guard against it then was to increase the viscosity of the milk by superheating and by raising the temperature in the sterilizer slowly. But even these precautions were no absolute guarantee against ultimate fat separation.

Since the introduction of the homogenizer, fat separation in evaporated milk is no longer a serious problem. As explained in Chapter XIII on "Homogenizing" the homogenizer, when used at pressures of from 2,000 to 3,000 pounds, divides the fat globules into such small units (about 1/10 of their original diameter), that they surrender much of their original buoyancy The increase of their surfaces is so great that the resistance thus encountered is only difficultly overcome by the force of gravity. The effect of gravity is diminished also because of the layer of non-fat material that is adsorbed to the surface of each of these minute globules, increasing their weight and diminishing the difference in specific gravity between fat globules and non-fat liquid.

Homogenization increases the viscosity of the evaporated milk somewhat. This further impedes the tendency of fat separation. In the case of milk rich in fat, such as is used in the manufacture of sterilized sweet cream, the increase in viscosity and the accompanying lowering of heat stability due to high-pressure homogenization are so marked as to cause serious sterilizing difficulties. It has been observed that homogenization tends to increase the number and density of fat clumps and it is believed that the increased viscosity and decreased heat stability in the homogenized product are in some way caused by this fat clumping. In a product with a fat content no higher than that of evaporated milk, however, the fat clumping effect of homogenization appears to be negligible and the heat coagulation point is not appreciably lowered. It has been suggested that the increased viscosity of homogenized evaporated milk, may be explained on the basis of increased volume of non-fat material adsorbed upon an enormously increased fat surface.

THE MILK PROTEINS

Kinds and Importance of Proteins in Milk.—The milk proteins make up approximately 3.4 to 3.8 per cent of the composition of average normal milk. Much wider variations are quite frequent. The principal milk proteins are the casein and albumin. Their properties are of great importance in the manufacture of condensed milk. It is the behavior of the proteins toward heat that determines the heat coagulation point of milk, which in turn is one of the controlling factors in the thickening of sweetened condensed milk with age and in the formation of a coagulum in evaporated milk when sterilized. Besides casein and albumin, milk contains small amounts of lactoglobulin and of alcohol-soluble protein. Globulin is present in colostrum milk in larger amounts. Only traces of these proteins are found in normal milk and they are not believed to play an important role in the physical-chemical structure and properties of normal milk.

Casein.—The casein is the chief protein of milk. The casein content of milk varies within wide limits. Van Slyke[124] shows that mixed market milk usually contains between 2 and 3 per cent casein. In milk from single herds the casein varies from about 1.80 to over 3 per cent. In single milkings from individual cows he found the casein to vary from 1.50 to 4.50 per cent.

The per cent casein in milk is influenced by breed, individuality of cow, period of lactation, feed, season, etc. Feed shortage, such as severe drought when cows depend on pasture for their exclusive feed supply decreases the casein content of milk. The period of lactation has a very marked effect on the quantity of casein present, see Table 15. The first milk drawn contains as high as 6 per cent or more casein. For the first 7 days there is a rapid decrease followed by a gradual decrease. From the second to the fourth or fifth months the per cent of casein is lowest. After that there is a slight increase up to about the ninth month when the casein increases more rapidly until the end of the lactation period.

The chemistry of casein has been the subject of study by many investigators. It is of highly complex nature, many phases of which are not as yet well understood and the names under which casein and the products derived from it are described are somewhat at variance.

Casein, also named caseinogen, as it is found in fresh milk, does not exist in the fresh milk in pure form. Söldner[125] showed that the casein of fresh milk is present in combination with calcium oxide. Fleischmann[126] found that the casein in fresh milk contains 1.55 per cent calcium oxide. These findings are supported by Van Slyke and Bosworth,[127] who state that the neutral substance as it occurs in fresh milk is calcium caseinate consisting of casein combined with 1.5 per cent calcium oxide.

Pure casein is the protein that remains after it has been separated from the calcium oxide. This separation occurs when the milk sours or when dilute acid is added to the milk. In the natural souring of milk the lactic acid combines with the calcium of the calcium caseinate forming calcium lactate. This reaction sets free the casein, precipitating it. In the resulting curd the fat and other milk constituents are also locked up but, after standing, much of the water and water-soluble constituents separate out in the form of whey. The pure casein is separated from milk by first removing the fat from the milk and then precipitating the casein with dilute acid, taking special precautions to remove all other milk constituents during operation and by subsequent washing.

Paracasein or calcium paracasein is the insoluble product (curd) obtained when rennet or rennet-like substances are added to the milk. In order for the paracasein to precipitate in the form of insoluble curd there must be present a sufficient amount of soluble calcium salts. In the absence of soluble calcium salts, as for instance in the case of milk in which the calcium salts have been rendered insoluble by heat, the paracasein will not precipitate, the milk will not curdle. In such cases the addition to the milk of a small amount of a soluble calcium salt, such as calcium chloride, will restore the curdling action of the rennet, or more correctly, it will precipitate the calcium paracasein formed by the action of the rennet. The coagulation of the paracasein may also be brought about and is hastened by the action of acid-forming bacteria or by direct addition of acid. The acid changes the calcium salts in milk into soluble form, thus subjecting the paracasein to the action of soluble calcium salts, the presence of which is necessary to precipitate the soluble calcium paracasein into insoluble calcium paracasein.

The casein molecule is made up of six elements. Fleischmann[126] shows the percentage composition of the elements of which casein is composed as follows:

Carbon	52.95%
Oxygen	22.78%
Nitrogen	15.65%
Hydrogen	7.05%
Phosphorus	.85%
Sulphur	.72%

As previously stated, the casein in fresh milk is present in combination with calcium oxide forming calcium caseinate. It reacts acid toward phenophthalein and toward bases in a similar manner as do acids, forming salt-like combinations. It is soluble in weak alkalies and strong acids and coagulates by the action of strong alkalies, weak acids, the salts of numerous metals, and rennet. It coagulates at ordinary temperature when the acidity of the milk reaches .6 to .7 per cent. As the temperature rises the percent acid required to coagulate the milk is diminished. Heat of pasteurization, because of precipitation of a portion of the soluble calcium salts, destroys its property to coagulate by rennet. Casein coagulates when milk is heated under pressure to 130-140° C. (266-284° F.).

Casein is of colloidal nature. It is colloidally dispersed in milk. It is present in milk in the form of very minute particles. These particles of calcium caseinate are believed to be highly hydrated, or saturated with the remainder of the milk serum, and being completely dispersed throughout the mass of milk, form a homogeneous emulsion. These colloidal particles pass through porous filters but can be separated from the skimmilk by filtering the milk through animal membrane, procelain filters, and other ultra filters.

Particle-Size of Casein.—According to the work of Svedberg, Carpenter and Carpenter[128] the molecular sizes of casein are of the order of a radius of 4 mμ. $\left(\frac{4}{1{,}000{,}000}\text{ mm.}\right)$. These investigators noted an increase in size of the casein molecule at 40° C. (104° F.). Nichols, Bailey, Holm, Greenbank and Deysher[129] studied the relation of particle-size of calcium caseinate of skimmilk, as affected by heat, to the heat stability of the milk. Their milk, including the control samples, had previously been heated to approximately 40° C. preparatory to skimming. They found the calcium casein particles in this milk to vary in radius from 100 mμ. $\left(\frac{1}{10{,}000}\text{ mm.}\right)$ to molecular sizes, and the mean radius to be 40 to 50 mμ. $\left(\frac{4}{100{,}000}\text{ to }\frac{5}{100{,}000}\text{ mm.}\right)$. Heating to 95° C. (203° F.), which is considered the optimum forewarming temperature for heat stability in evaporated milk, very slightly decreased the particle-size from a mean size of 45 mμ. $\left(\frac{45}{1{,}000{,}000}\text{ mm.}\right)$ in the unforewarmed control samples, to a mean size of 41 mμ. $\left(\frac{41}{1{,}000{,}000}\text{ mm.}\right)$ in the milk forewarmed at 95° C. for 10 minutes. They consider this indication of a slight shift in the mean radius to a smaller particle-size as differences falling within the experimental error, but concede the possibility that the particles may increase progressively in size with time and temperature of heating, particularly in the later stages. They conclude on the basis of their results, however, that the particle-size distribution of calcium caseinate is very little affected by forewarming up to 95° C. for a short time.

Albumin.—The albumin, milk albumin, or lactalbumin is present in milk to the extent of approximately .6 per cent. The per cent albumin in milk varies even more than the per cent casein, the variations, however, are in the same direction. It is highest in milk immediately after calving. Hunziker,[94] who studied the albumin content of three cows during their entire period of lactation, found that the first milking after calving contained between 6.0 and 7.0 per cent albumin. At the end of the second day it had dropped to below 1 per cent, though the average for the 14 days was .98, 1.59 and 1.78 per cent, respectively, for the three cows. It decreased further until toward the end of the first month it had dropped to the minimum and stayed at the minimum until the end of the sixth month. Then it rose gradually until at the ninth month the milk contained close to 1 per cent albumin. The variations ranged from a minimum of .44 per cent to a maximum of 6.63 per cent albumin. The average for all three cows for their entire periods of lactation after the first 14 milkings after calving was .62 per cent.

Chemically the albumin differs chiefly from the casein in that it contains no phosphorus and that its sulphur content is nearly two and one-half times as great as that of casein. Fleischmann[126] shows the following composition of albumin:

Carbon	52.19%
Oxygen	23.13%
Nitrogen	15.77%
Hydrogen	7.18%
Sulphur	1.73%

The properties of milk albumin are similar to those of blood albumin. It is believed to be present in milk in the form of colloidal dispersion and exists in milk uncombined with base. Palmer [130] found that the milk albumin is highly hydrated and in a highly dispersed state.

Milk albumin is soluble in water, and in dilute acids and dilute solutions of sodium chloride and sodium carbonate. It is coagulated by heat. According to Rupp[131] exposure to 62.8° C. (145° F.) for 30 minutes does not coagulate it; exposure to 65.6° C. (150° F.) coagulates 5.71 per cent; 68.3° C. (155° F.) coagulates 12.76 per cent; and exposure to 71.1° C. (160° F.) coagulates 30.86 per cent. At the boiling point practically all the albumin of milk coagulates, the per cent albumin not precipitated by heat at this temperature amounting to .14 to .16 per cent as shown by Hunziker.[94]

Other nitrogenous constituents that have been found in milk are lactoglobulin, fibrin, mucoid protein, lecithin and nuclein. In normal milk these milk proteins are present in very small amounts only. Lactoglobulin coagulates upon heating and fibrin upon exposure to air. These two proteins are found in considerable quantities in colostrum milk, but normal milk contains only traces of them. Mucoid protein has been isolated from butter by Storch.[132] Lecithin is a nitrogenous substance associated with the milk fat. It contains phosphorus and has the formula $C_{42}H_{84}NPO_9$. Its decomposition is claimed to be responsible for the fishy flavor of butter. Nuclein is associated with the casein. Comparatively little is known concerning these milk proteins, they are found in milk in traces only and are not believed to affect the behavior of milk in the condensing and sterilizing process.

Role of Properties of Milk Proteins in Manufacture of Condensed Milk.—As pointed out in Chapter XV, "Effect of Proteins on Heat Coagulation," the proteins of milk play an important part in the heat coagulation of milk and through this channel largely control the thickening of sweetened condensed milk and the curdling of evaporated milk in the sterilizer.

In previous paragraphs it was shown that the casein is present in fresh milk as calcium caseinate. Sommer and Hart[83] demonstrated that the heat coagulation point of fresh milk and also of evaporated milk is influenced, if not controlled, by the calcium-casein balance, that casein requires a definite optimum calcium content for its maximum stability and that the calcium content of the casein is largely controlled by the magnesium, citrates and phosphates present. In practically every case of abnormal curdling of evaporated milk in the sterilizer the difficulty seemed to be caused by excess calcium, and when sodium citrate or di-sodium phosphate was added to the milk the heat coagulation point was raised and sterilizing trouble avoided. The addition of citrates and phosphates, in such cases makes the casein more stable by reducing the excess of available calcium and thereby bringing about the desired calcium-casein balance.

The fact that the forewarming of milk to high temperatures 95° C. (203° F.) materially raises the heat coagulation point of evaporated milk, as shown by Rogers and co-workers,[33] may logically be attributed to a readjustment of the calcium-casein balance. Rogers found that forewarming at 95° C. usually raises the coagulating temperature of evaporated milk 15 to 30° C. (27 to 54° F.) and that holding at the forewarming temperature for 10 and 20 minutes raised the coagulating temperature 3 and 6° C. (5.4 and 10.8° F.) respectively.

Milroy[74] found that heating milk to high temperatures precipitates part of the calcium. This reduces the soluble calcium available to react with the casein. It improves the calcium-casein balance and stabilizes the casein. Rogers suggests that while the major part of the calcium precipitation was brought about by heating to 95° C. (203° F.), there was continued small precipitation when the milk was maintained at this temperature, hence the further raising of the heat coagulation point upon prolonged forewarming at 95° C.

The fact that such factors as increase in concentration of the milk (which means higher casein content), and the presence of developed acid and of rennet or rennet-like substance, lower the heat coagulation point, is further evidence of the important role which the casein plays in determining the behavior of evaporated milk in the sterilizer.

The albumin of milk also may be expected and has been shown by Sommer[92] to influence the heat coagulation point of evaporated milk. As previously pointed out albumin is readily coagulated by heat and Sommer's work has demonstrated that an increase in the albumin content lowers the coagulation temperature of evaporated milk. Because of this fact it is probable that the stabilizing effect of high forewarming temperatures is in part at least due to the precipitation of the albumin. Sommer showed that raising the preheating temperature of evaporated milk from 180 to 212° F. lowered the per cent soluble albumin from .86 per cent to .56 per cent and that the time required for coagulating the milk at 245° F. was 9 minutes longer for the milk forewarmed at the higher temperature. These results would indicate that the effect of forewarming temperature is due, in part at least, to the precipitation of the albumin.

Both the casein and the albumin also play an important part in the progressive thickening of sweetened condensed milk after manufacture. This thickening tendency is most pronounced in the case of condensed milk manufactured in the spring of the year when the bulk of the milk supply comes from recently freshened cows and when the albumin and casein content of the milk tend to be relatively high. This is also the time of the year when the pan operator is often troubled with a deposit and accumulation of a thick gelatinous-like coating of semi-solid condensed milk cooked on to the surface of the steam coils in the vacuum pan. Milk made in late fall, winter and early spring shows much less tendency toward thickening in storage, and the formation of an objectionable jelly-like coating on coils and jacket of the pan does not occur.

Rogers and co-workers[64] demonstrated that the increase in concentration of these proteins increases the rapidity and extent of thickening with age. The removal of either the casein or the albumin reduced the viscosity and retarded the later thickening. The reduction in viscosity was greater in the absence of the casein than in the absence of the albumin. The removal of both stopped the thickening completely. These results further showed that high forewarming temperatures, not exceeding the boiling point, greatly increased the viscosity and the thickening tendency, while low forewarming temperatures (145.4° F. for 30 minutes) diminished the viscosity and the thickening tendency. At temperatures above the boiling point, 110 and 120° C. (230 and 248° F.) the stability increased.

The above findings are corroborated also by the results of Stebnitz and Sommer[35] who found that at forewarming temperatures up to 165° F. there is practically no effect on thickening in storage, but that above these temperatures the thickening tendency increased rapidly with an increase in temperature up to 210° F. Forewarming temperatures above the boiling point increased the stability and diminished age-thickening.

The proteins of milk play an important role also in the brown discoloration of sweetened condensed milk and evaporated milk. It appears that, in the presence of the heat employed in manufacture and when stored at relatively high temperatures, interaction takes place between the sugar of milk and certain protein groups that is accompanied by and responsible for the darkening of the condensed milk. For details see "Color of Milk" discussed later in this chapter.

THE ASH OF MILK

Composition of Ash.—The ash or mineral content of milk amounts to about .7 per cent of the composition of milk. The ash content is highest in the colostrum milk. Engling-Leach[134] show the per cent ash in milk during the first 72 hours after calving. Immediately after calving the milk contained 1.18 per cent ash, after 10 hours 1.55 per cent. From then on it decreased rapidly and was .82 per cent after 72 hours. Hills[135] reports that

German analyses give the maximum ash content of 22 cows, milked immediately after calving, at 2.31 per cent. The ash content of milk after the first 14 milkings is quite uniform, ranging between about .65 to .75 per cent and averaging .7 per cent throughout the period of lactation and to within a short time before the cows dry up. It is, in fact, the most constant constituent of cow's milk, and because of this the average ash content of .7% furnishes a reasonably dependable basis for calculating the ratio of concentration of the condensed product, which is determined by dividing the ash content of the latter by the factor 0.7.

The ash of milk consists chiefly of potassium, sodium, calcium and magnesium, combined with phosphoric acid, hydrochloric acid and citric acid. A portion of the lime is combined with the proteins. There are also present small amounts of iron and sulphur.

Babcock[134] gives the composition of ash as follows:

Table 33.—Composition of Ash in Normal Cow's Milk

Mineral Constituents in Milk	In Ash Per Cent	In Milk Per Cent
Potassium oxide (potash)	25.02	.175
Sodium oxide (soda)	10.01	.070
Calcium oxide (lime)	20.01	.140
Magnesium oxide (magnesia)	2.42	.017
Iron oxide (ferric)	.13	.001
Sulphur trioxide	3.84	.027
Phosphoric pentoxide	24.29	.170
Chlorine	14.28	.100
Total ash	100.00	.700

Söldner[125] suggests the following grouping of the milk salts:

Sodium chloride, $NaCl$	10.62
Potassium chloride, KCl	9.16
Mono-potassium phosphate, KH_2PO_4	12.77
Di-potassium phosphate, K_2HPO_4	9.22
Potassium citrate, $K_3(C_6H_5O_7)_2$	5.47
Di-magnesium phosphate, $MgHPO_4$	3.71
Magnesium citrate, $Mg_3(C_6H_5O_7)_2$	4.05
Di-calcium phosphate, $CaHPO_4$	7.42

Tri-calcium phosphate, $Ca_3(PO_4)_2$	8.90
Calcium citrate, $Ca_3(C_6H_5O_7)_2$	23.55
Lime, combined with proteins	5.13

Importance of Salt Balance.—As explained under "Proteins of Milk" earlier in this chapter, the mineral constituents of milk have a decided influence on the heat coagulation point of condensed milk.

The percentage composition of the several mineral constituents varies considerably with individual cows, period of lactation and feed, so that the salt-casein balance is subject to many fluctuations. Available experimental data on this subject, while not entirely concordant, indicate that the calcium and phosphorus content of milk tends to be highest at the beginning and especially toward the end of the period of lactation and lowest when the lactation is at its height. That this condition does not necessarily alter the heat coagulation is shown by Sommer and Hart[69] who point out that an increase of both calcium and phosphorus might not change the salt balance in so far as its effect on heat stability is concerned. However, Trunz[136] who also observed the above seasonal increase in calcium and phosphorus further found that the calcium content was highest in proportion to the phosphorus content at the beginning and end of the lactation period, and lowest during the middle. This condition would suggest the tendency toward a calcium excess at the beginning and end of the period of lactation, that would depress the heat coagulation point.

Webb and Holm[87] demonstrated experimentally that cations other than calcium can have the same effect as the calcium ion. They concluded, therefore, that the effect of an excess or a deficiency of calcium on heat stability is not the result of the calcium itself, but that it is due to the positive charges which this ion carries. They envision the stabilizing of milk as a problem of balance between positively and negatively charged electrolytes. Their findings of the balance in particle charge as the basis for maximum heat stability of milk confirm the salt balance theory of Sommer and Hart to the effect that the calcium and magnesium (which represent the ions with positive charges) must be balanced by the phosphates and citrates (which are the negatively charged electrolytes) to accomplish maximum heat stability.

Feeding experiments by Sommer and Hart[69] showed that in case of an excess of calcium the salt balance may be improved and the heat coagulation temperature raised by the feeding of green feeds, which increased the citric acid content of milk. Efforts to increase the calcium content of milk by feeding calcium salts, however, gave negative results and failed to alter noticeably the heat stability.

For detailed discussion of salt balance and heat coagulation see "Proteins of Milk" in this chapter, and "Factors Influencing Heat Coagulation," Chapter XV.

THE SUGAR OF MILK

Lactose Content of Milk.—Milk sugar, lactose, is the chief carbohydrate of milk. It is present in average, normal milk to the extent of approximately 4.8%. It is the least variable constituent of milk except the ash. Its percentage is far more constant than that of the fat and protein. While in rare cases samples of milk have been found to contain as little as 2.41% and slightly above 6.0% lactose, such variations are extremely rare. In mixed herd milk the lactose content is usually confined to the limits of approximately 4.75% to 5.0%. There appears to be no marked difference in lactose content of milk between the different dairy breeds, and the per cent lactose runs remarkably uniform throughout the lactation period.

Milk Sugar Crystals.—Lactose crystals are of complex crystallographic structure. They belong to Class C_2. They are monoclinic sphenoidal and have only one axis of symmetry. They have trapezoidal side faces and rhombic tops and bottoms. The fully developed lactose crystal has, in addition, beveled faces at base and apex which may terminate in a sharp edge giving the crystal a distinct tomahawk appearance. It may have ten faces and its length is approximately 1.8 times its width at its widest portion.

Hunziker and Nissen[137] demonstrated experimentally that fully developed typical lactose crystals, as described above, are characteristic of the crystals obtained from supersaturated lactose solutions in water, in skimmilk, in whole milk, in milk serum, and in plain condensed milk (unsweetened). It appears evident, therefore, that the presence in the milk sugar solution

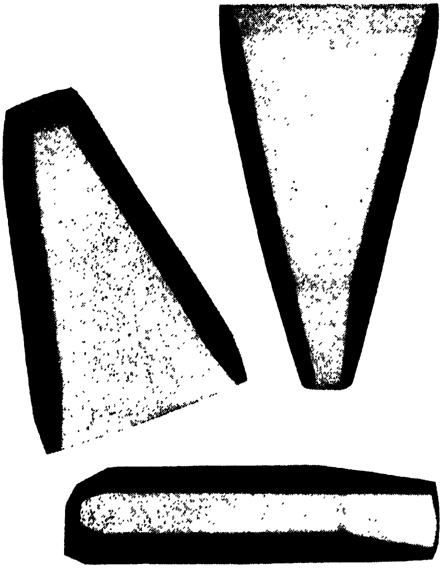

Fig. 92. Lactose crystals

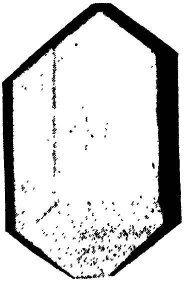

Fig. 93. Sucrose crystal

Microphotographs

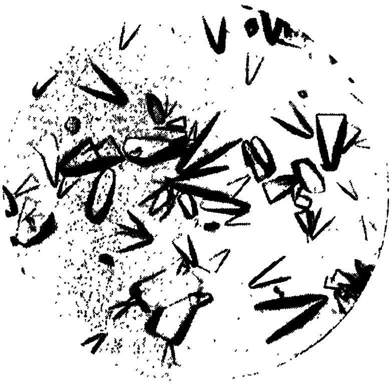

Fig. 94. Lactose crystals from pure lactose solution, mag. X 230

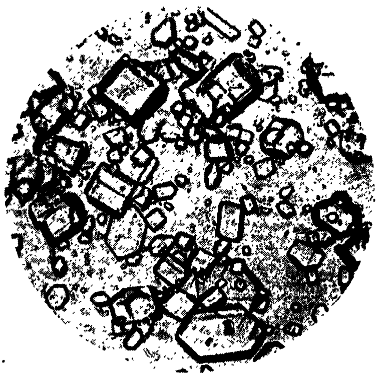

Fig. 95. Sucrose crystals from pure sucrose solution, mag. X 130

Microphotographs

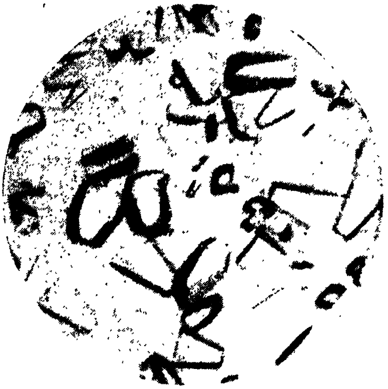

Fig. 96. Lactose crystals from 14% sucrose solution, mag. X 160

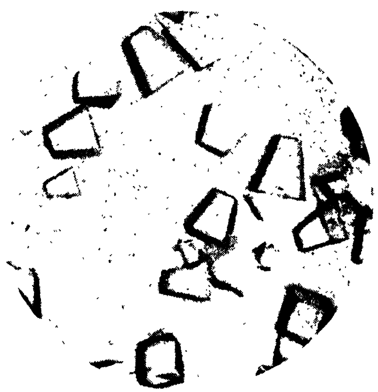

Fig. 97. Lactose crystals from 62% sucrose solution, mag. X 160

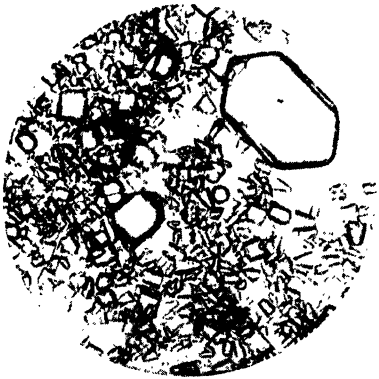

Fig. 98. Lactose and sucrose crystals from supersaturated solutions of both sugars, mag. X 45

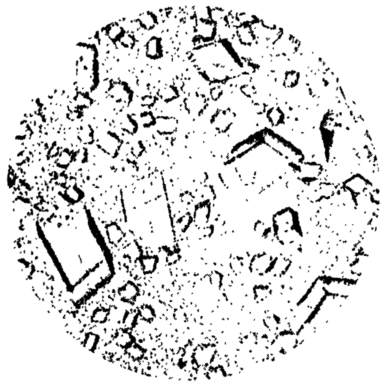

Fig. 99. Lactose crystals in sandy sweetened condensed milk, mag. X 130

Microphotographs

of milk colloids and milk fat does in no way modify the appearance or the structure of the lactose crystal obtained.

The presence of sucrose in the supersaturated lactose solution causes an apparent modification of lactose crystals. In the case of dilute sucrose solutions, such as solutions containing 14% sucrose, the change is only slight, the lactose crystals being fully developed, but they are shorter and thicker than the crystals from solutions containing no sucrose. This is the type of lactose crystals found in sandy ice cream. In concentrated sucrose solutions, such as solutions containing 62% sucrose, the change in the appearance of the lactose crystal is very marked. The crystals resemble short, truncated pyramids with flat rhomboid bases and apexes, the beveled faces at base and apex being entirely absent. This is the type of crystal found in normal sweetened condensed milk. In "sandy" sweetened condensed milk the above crystal forms are interspersed with relatively large diamond shaped crystals, such as Williams and Peter[138] have found in "sandy" ice cream, and which they have identified as alpha lactose hydrate.

Under "Sucrose" it will be shown that, while concentrated sucrose solutions modify the appearance of the lactose crystal, supersaturated solutions of both sugars do not yield a mixed crystal of both lactose and sucrose.

Modifications of Milk Sugar.—Lactose, $C_{12}H_{22}O_{11}+H_2O$, is known to exist in the form of three modifications, namely: the alpha hydrate or mono hydrate, the beta anhydride and the alpha anhydride. The relationship of these three modifications was studied by Hudson[139] and Gillis[140].

The Alpha Hydrate, or mono hydrate milk sugar is the normal product which is crystallized from milk sugar solutions at ordinary temperature. It is the milk sugar of commerce. Its formula is $C_{12}H_{22}O_{11}+H_2O$. As the formula shows, the alpha hydrate contains one molecule of water. It contains 5% water of crystallization, which it retains even when heated to 100° C. (212° F.). According to Whittier[141] "lactose may be heated to 110° C. (224° F.) without change, but between 110° C. and 130° C. (224° F. and 266° F.) it loses all its water of crystallization." Prolonged heating above 100° C. and up to 130° C. causes the milk sugar to take on a light brown color, decomposition sets in, the sugar taking on oxygen and giving off carbon dioxide. As the temperature increases the decomposition progresses and the sugar darkens in color. At 170 to 180° C. (338 to 356° F.) it forms lacto-caramel, which is deep brown in color and has a peculiar odor. It melts at 203.5° C. (398° F.). Milk sugar has a specific gravity of 1.545 and its specific heat is .30. It is much less sweet to taste and its solubility is only about one-eleventh of that of sucrose.

In aqueous solutions milk sugar is converted into lactic acid by the action of lactic acid bacteria. Theoretically one molecule of milk sugar yields four molecules of lactic acid, as shown in the following equation:

$$C_{12}H_{22}O_{11} \cdot H_2O = 4C_3H_6O_3.$$

In the lactic acid fermentation of milk, however, the amount of lactic acid produced is far less than that indicated by the above theoretical equation. This is due to the formation, in addition to lactic acid, of other substances, such as carbon dioxide, hydrogen, butyric acid, water, etc. As shown in the discussion of the properties of casein, when the milk sours, a portion of the lactic acid combines with the calcium forming calcium lactate. This sets free the casein and causes it to coagulate.

The presence in milk of .20 per cent lactic acid or more gives the milk a noticeable sour odor. At an acidity of .25 per cent the milk begins to taste sour and when the acidity reaches .5 to .7 per cent, the milk curdles at ordinary temperature. The ordinary types of lactic acid bacteria, such as Streptococcus lactis, are capable of developing acid in milk to the extent of approximately .95 per cent. At this high acidity their action ceases. But other forms of bacteria, such as Bacillus bulgaricus and Bacillus acidophilus are capable of producing 2 to 3 per cent acid in milk. The titratable per cent acid which the ordinary species of lactic acid bacteria, such as are used for butter culture, attain depends to some extent on the presence or absence of casein. Tests by Hunziker[142] demonstrated that in normal milk an acidity of between .95 to 1.05 per cent may be attained while in whey from the same milk the acidity produced by the ordinary variety of lactic acid bacteria will not rise above approximately .7 per cent. This phenomenon may be explained by the fact that these lactic acid bacteria find a medium containing as high as about .7 per cent acid unfavorable for further development. In normal milk the calcium of the calcium caseinate inactivates a part of the lactic acid, so that the lactic acid bacteria may be able to continue their action upon the lactose beyond this limit of .7 per cent. In whey there is practically no casein, hence all of the acid produced remains as lactic acid, rendering further development impossible.

Certain species of yeast are capable of fermenting milk sugar, forming carbon dioxide and alcohol. Torula cremoris and Torula sphaerica, described by Hammer and Cordes[143], ferment lactose rapidly at high temperatures. These organisms cause the foaming of cream in summer. Investigation by Hunziker[144] shows that they are capable of completely destroying the milk sugar in cream in from 60 to 72 hours, when incubated at 95° F. The fermentation of lactose by the combined action of yeast and lactic acid bacteria such as Bacterium Caucasus which accompanies the yeast of the Kephir grains forms the basis in the manufacture of Kephir and Koumiss.

The milk sugar of commerce finds extensive use for dietary, therapeutic and medicinal purposes. If consumed in such quantities that the lactose is not all split in the small intestine, the excess may be utilized by lactose-fermenting bacteria, changing the flora of the large intestine from a putrefactive type to a fermentative type, such as Lacto-bacillus acidophilus. This change is usually accelerated if cultures of this organism are fed with the lactose. Beneficial results are obtained by a diet of this combination in the treatment of autointoxication. The therapeutic value of lactose embraces also its pronounced laxative and diuretic effects. Its ease of digestion and assimilation recommends its use in the diet of consumptives and individuals suffering from wasting diseases.

Lactose plays an important part in the modification of milk for infant feeding, and it is extensively used in the preparation and as a diluent, vehicle and sweetener of pharmaceutical products such as pills, tablets and the like. Lactose is used also by confectioners in certain types of candies and fondants, and by manufacturers of special liqueurs on account of the frosty appearance produced by crystallization of the sugar on the inside of the bottles.

The Beta Anhydride sugar is the anhydrous modification of the alpha hydrate, or milk sugar of commerce. The hydrate sugar is only sparingly soluble. Its solubility is called the initial solubility. When dissolved in water a portion of the hydrate changes to the beta anhydrous form, when more of the hydrate sugar dissolves. At temperatures below 93° C. (199° F.) an equilibrium is reached when there is present in solution about 1 part of the hydrate to 1½ parts of the beta anhydride. This equilibrium property of beta anhydride plus the total amount of hydrate sugar dissolved is called the final solubility.

The Alpha Anhydride modification is formed when the hydrated milk sugar is heated at 125° C. to constant weight.

Alpha anhydride is unstable. With water it changes immediately back to the hydrate solution.

Milk Sugar in Condensed Milk.—To what extent the chemical properties of milk sugar undergo changes in the manufacture of condensed milk is as yet somewhat uncertain. It is well known that prolonged exposure of evaporated milk to sterilizing heat (240° to 245° F.) causes a brown discoloration. Furthermore, the storage of both evaporated and sweetened condensed milk above room temperature brings about a darkening in color. Recondensing of sweetened condensed milk or of evaporated milk with fresh milk also gives the finished product a color much darker than normal. It is conceivable that in the case of evaporated milk the brown discoloration resulting from prolonged sterilization may be due, in part at least, to oxidation leading to partial caramelization. Under "Color of Milk," discussed later, it will be shown, however, that an increase in forewarming temperature likewise produces an increase in color and hastens the browning of sweetened condensed milk with age, especially when stored at relatively high temperatures. Yet milk sugar is not known to undergo caramelization at temperatures below the boiling point.

As shown under "Color of Milk," lactose, because of its active ketone group, is capable in the presence of heat of reacting with the milk proteins, particularly with certain amino-acid groups. This interaction has been found to yield sugar-protein complexes which themselves show a brown discoloration. It appears reasonable to assume, therefore, that at least a portion of the lactose may undergo chemical changes of this nature.

Of the physical properties of milk sugar and their effect on condensed milk, the relatively low solubility of lactose is the most important factor. In the case of plain condensed milk used for the manufacture of ice cream the concentration may be carried to a point where there is not sufficient water left to keep the milk sugar in solution. This causes it to crystallize out and to give the concentrated milk a gritty, sandy texture. Unless this gritty condensed milk is heated to dissolve the crystals, and properly diluted before the mix is frozen, the ice cream is prone to be gritty. In the case of sweetened condensed milk the milk sugar content is much too high, in proportion to the limited amount of water present, to remain in complete solution. A large portion of the milk sugar in this product is present in the form of crystals. If these crystals exceed a certain size the product becomes gritty to the taste and a deposit forms in the bottom of the package. Sandiness and sediment here can be avoided by the proper control of the cooling process. The fundamental essentials to accomplish this are to provide conditions conducive to rapid precipitation of the greatest possible number of small individual crystals, thereby reducing the unstable state of supersaturation to the more stable state of saturation and thus preventing the subsequent formation and growth of large crystal aggregates. These facts are important. A clear understanding of the science of milk sugar crystallization is essential in efforts to successfully guard against sandiness and sugar deposit in sweetened condensed milk. The details are discussed in succeeding paragraphs.

The Solubility of Milk Sugar.—By far the most comprehensive data on the solubility of milk sugar are furnished by Hudson.[139, 145] The results of Hudson's extensive investigation have served as the basis for all subsequent study of the subject. According to Hudson's findings the sugar of milk may be considered to have three points of solubility, namely, initial solubility, final solubility, and super solubility. Hudson's figures for initial and final solubility of milk sugar at different temperatures are assembled in Table 34.

Table 34.—Initial and Final Solubility of Lactose

(Based on lactose anhydride $C_{12}H_{22}O_{11}$ and not the hydrated form $C_{12}H_{24}O_{12}$.)

Temperature		Initial Solubility		Final Solubility	
° C.	° F.	Lactose per cent	Parts Lactose to 100 parts of water	Lactose per cent	Parts Lactose to 100 parts of water
0	32	4.8	5.0	10.6	11.9
15	59	6.8	7.3	14.5	16.9
25	77	8.2	8.9	17.8	21.6
39	102	11.0	12.4	24.0	31.5
49	120	15.0	17.6	29.8	42.4
64	147	21.0	26.6	39.7	65.8
74	165	26.0	35.1	46.3	86.2
89	192	37.0	58.7	58.2	139.2

Initial Solubility.—When ordinary powdered milk sugar, the alpha hydrate, is placed in water and vigorously shaken in order to secure a saturated solution rapidly, a certain portion of the sugar dissolves immediately. The amount that goes into immediate solution represents the initial solubility of the hydrate form of lactose. The initial solubility, however, is temporary only, as the lactose that has gone into solution changes to beta anhydrous lactose and this change continues until a ratio of 1.58 beta to 1 alpha lactose is attained. This change is progressively decreasing the amount of alpha lactose in solution. It reduces the state of saturation to undersaturation, causing more lactose to go in solution.

Final Solubility.—In the presence of continuous shaking the change of alpha to beta lactose and the progressive solution of alpha lactose continue until equilibrium is reached. This occurs when the ratio of beta to alpha lactose is 1.58 to 1 (at 25° C.) and the alpha lactose represents a saturated solution. The amount of lactose that is in solution at this final point represents the final solubility. The initial and final solubilities vary with temperature as shown in Table 34 and in chart Fig. 48.

Supersolubility.—When a saturated solution is cooled below the temperature of saturation it becomes supersaturated. If the cooling is done moderately only, crystal nuclei often do not form immediately, the solution maintaining its supersaturation for a prolonged period of time. When the cooling is continued to lower temperatures crystallization will set in and, when once initiated, will spread through the entire mass. Cooling below the temperature of saturation is called super-cooling and the state of solubility that exists in a supercooled solution is termed supersolubility.

Ostwald[146] names that state of supersolubility in which nuclei of crystals do not readily form a "meta-stable" condition, and that state of condition induced by further supercooling which results in crystallization, a "labile" condition.

The meta-stable area extends over a considerable temperature range. At the higher temperatures it borders the saturation area or final solubility curve. At the lower temperatures it is limited by the labile area or supersolubility curve.

In the meta-stable area or condition, crystallization can usually be induced only by liberal seeding with the material, or with substances containing the material, or with any substance other than the material, but that is isomorphous (of similar form). In the case of sweetened condensed milk, for instance, crystallization of the milk sugar present in excess of saturation in the meta-stable area can be induced by the addition of a small amount of milk sugar crystals, or of a little sweetened condensed milk of a previous day's batch.

When crystals form in the supersaturated solution, either as the result of the addition to and presence in the solution of nuclei in the meta-stable area, or because of continued supercooling to lower temperatures, or because of vigorous agitation, the crystals so formed are of the alpha hydrate form, because of the lower solubility of alpha lactose than beta lactose. Alpha lactose crystallizes from solutions below 93° C.

As the hydrate crystals precipitate, more of the beta anhydride form changes back to the hydrate sugar, thus maintaining the equilibrium between hydrate and anhydride sugar in solution, which, as shown in previous paragraphs is 1 to 1.58, respectively, at 25° C. Crystallization thus continues until the supersaturation has been reduced to the point of saturation at that temperature, when the solution becomes a stable, saturated solution.

Hudson showed that the point of saturation at a given temperature is the same whether reached upward, by prolonged mixing of an excess of milk sugar with water until the point of final solubility is attained; or determined downward, by recrystallization of the excess sugar in a supersaturated solution upon cooling to the same temperature. Similar results were obtained by Hunziker and Nissen.[147]

Hallimond[148] shows that there are three main principles that enter into and must be given consideration in a theory of the relation of crystallization to supersaturation, as shown in the following quotation:

"The first concerns the existence, below the ordinary solubility curve for each constituent, of a range of temperature and concentration within which crystallization is only initiated upon the introduction of a suitable nucleus.

"The second is that the rate of growth of a crystal at first increases as the temperature falls below that of equilibrium (saturation) and then diminishes when a certain degree of supercooling is exceeded.

"The third is that the redistribution of heat and of dissolved matter, consequent on and essential to solidification at the surface of a growing crystal, is governed by gradients of temperature and concentration, which depend in their turn upon the respective coefficients of heat conductivity and of diffusion."

Another important point in the control of crystallization in supersaturated solution is the fact brought out by Miers and Isaacs,[149] that each foreign substance used for seeding has a characteristic temperature at which it is capable of initiating crystal growth. This indicates that the temperature concentration curve describing the boundary line between the meta-stable and labile areas, will vary with each foreign substance added.

The above investigators also show that it is possible to have growing crystals in the meta-stable area that do not cause a general crystallization and Hallimond suggests that the true supersaturation point or inoculation point represents a definite temperature above which crystallization will not occur, even upon indefinitely slow cooling.

Leighton and Peter[150] describe the velocity of crystallization as follows: "The linear crystallization velocity at first increases with supercooling, then remains constant, and finally diminishes more or less sharply with falling temperature, probably owing, in the first place, to the usual increase in speed of a reaction with departure from equilibrium and, in the second place, to the increase of viscosity and diminution of reaction velocity with falling temperature. The continued growth of a crystal is conditional on the maintenance of a supply of material by diffusion, and on the dissipation of the latent heat developed in crystallization."

Significance of Meta-stable Area in Supersaturated Sugar Solutions as Applied to Sweetened Condensed Milk.—It has long been known by physicists that milk sugar, as well as many other organic and some inorganic compounds are capable of forming supersaturated solutions, as shown by Lieben,[151] Dubrunfaut,[152] Hudson,[145] Hudson and Brown,[153] and especially by Miers and Isaacs[149] and Hallimond.[148] Miers who experimented with sodium nitrate solutions shows that it was necessary to stir a solution vigorously and for a long time in order to reduce it from a supersaturated solution to a saturated condition. By slow cooling crystals in a supersaturated solution of sodium nitrate did not form until the labile state was reached. With continuous shaking and regular cooling crystals always appeared at this point. But by rapid cooling it was possible to reduce solutions to a temperature far within the labile region without crystallization taking place. Hallimond, experimenting with calcium nitrate and other salt solutions, reports that a thin shower sometimes appeared when a solution was shaken in the meta-stable state owing probably to chance inoculation. If not shaken or stirred, the more viscous solutions could be brought far into the labile state without crystals appearing, while heavy seeding with crystalline substances induced and enhanced crystallization in the meta-stable state. By sufficiently rapid cooling the number of nuclei was diminished.

Leighton and Peter[150] experimented with lactose solutions of varying concentrations. These solutions, placed in stoppered bottles and seeded with bits of glass, were rotated in the thermostat. The temperature was lowered a few degrees every 24 hours and the time at which the different bottles crystallized was noted. These investigators thus found that the supersolubility curve of lactose lies in the neighborhood of 30° C. (54° F.) below the final solubility curve. This discovery by Leighton and Peter is important. It explains theoretically and scientifically many of the phenomena observed in practical manufacture of sweetened condensed milk. It laid the groundwork for the systematic development of methods of cooling this product that have been of constructive help in the uniform prevention of sandiness. For prevention of sandy and settled condensed milk, see Chapter XXV.

For details of control of lactose crystallization in commercial manufacture see "Cooling Sweetened Condensed Milk," Chapter IX, and "Sandy Sweetened Condensed Milk," Chapter XXV.

Effect of Other Milk Constituents and of Sucrose on Lactose Solubility.—The influence of milk fat, milk solids not fat and sucrose on the solubility of lactose was studied by Hunziker and Nissen.[147] Their results of lactose solubility tests with skimmilk and whole milk indicate that neither the milk fat nor the milk colloids have any appreciable influence on the solubility of lactose. Sucrose, however, appears to diminish the solubility of lactose somewhat. This effect increases with an increase in sucrose concentration, as shown in Table 35.

Table 35.—Lactose Solubility Averages*

Kind of Solution	Temperature	Average of Best Results		Average of All Figures	
		Percent lactose in water part of solution	Grams lactose to 100 grams of water in the solution	Percent lactose in water part of solution	Grams lactose to 100 grams of water in the solution
	° F				
Lactose in water	50	13.02	14.97	13.02	14.97
Lactose in water	65	15.50	18.34	15.97	19.01
Lactose in whole milk	65	15.50	18.34	15.87	18.86
Lactose in skimmilk	65	15.50	18.34	15.90	18.95
Lactose in water containing 14 per cent sucrose	50	12.63	13.93	12.63	13.93
Lactose in water containing 14 per cent sucrose	65	14.95	17.60	15.16	17.88
Lactose in whole milk containing 14 per cent sucrose	65	14.77	17.30	15.25	17.98
Lactose in skimmilk containing 14 per cent sucrose	65	14.70	17.30	14.89	17.46
Lactose in water containing 62 per cent sucrose	65	13.20	15.20	13.46	15.55
Lactose in milk containing 62 per cent sucrose	65	13.45	15.50	13.45	15.50
Lactose in supersaturated sucrose-water solution	65	14.49	16.94		
Lactose in supersaturated sucrose-milk solution	65	14.01	16.30		
Lactose in water (by Hudson)	50	13.06	15.02		
Lactose in water (by Hudson)	65	15.54	18.40		

*The results given in the second and third columns of the table are considered somewhat more accurate and were obtained after the method of procedure had become well established. However, the averages of all results as given in columns four and five of the table are not seriously at variance with former figures and with those by Hudson.

Sucrose.—All sweetened condensed milk contains a considerable percentage of added sucrose. The fundamental purpose of the presence of sucrose in this product is to preserve it. The sucrose content in sweetened condensed milk of commerce varies from about 37 to 46 per cent, and the sucrose-in-water ratio is approximately from 59 to 64.5 per cent.

The solubility of sucrose at different temperatures is shown in Table 12. At 68, 59, 50 and 32° F. saturation is reached at concentrations of 67.09, 66.3, 65.58, and 64.18 per cent sucrose, respectively. When the sucrose-in-water concentration of sweetened condensed milk exceeds 65 per cent there is danger of the development of sandiness at low storage temperatures (45° F. or below) on account of the formation of sucrose crystals due to supersaturation of the sucrose-in-water solution.

In contra-distinction to the lactose crystals previously described and illustrated, the sucrose crystals, while also monoclinic sphenoidal, present a vastly different appearance. They do not have pyramidal form, all their faces being rhomboid and all opposite sides generally being parallel. Unlike the lactose crystals, the sucrose crystals grow to relatively large size and have a marked tendency to twine together, a characteristic foreign to lactose crystal formation. These differences in appearance are very noticeable where lactose and sucrose are allowed to crystallize out from solutions supersaturated with both sugars.

Such solutions yield typical crystals of each sugar independent of each other. The crystals found in sweetened condensed milk of normal sucrose concentration (sucrose concentration below saturation point) are pure lactose crystals. They are not sucrose crystals, nor mixed or composite crystals of both sugars. However, as pointed out under "Milk Sugar Crystals," the presence of sucrose in supersaturated lactose solutions does change the appearance of the lactose crystal, and this modification in crystal form increases with an increase in sucrose concentration.

The presence of sucrose diminishes the solubility of the lactose to some extent. This effect is only slight in dilute sucrose solutions (14% sucrose) but becomes quite noticeable in higher sucrose concentrations (62% sucrose), such as prevail in sweetened condensed milk, as shown by Hunziker and Nissen[147] whose results are summarized in Table 35.

Dextrose.—Within the past decade the use of dextrose in the manufacture of sweetened condensed milk has received extensive consideration. Results of experiments by several investigators show that by the proper modification of the process of condensed milk manufacture a portion of the sucrose may be substituted with dextrose. In commercial manufacture, so far, this substitution of sucrose with dextrose has been made use of only in the case of sweetened condensed milk sold in bulk to bakers, confectioners, candy and ice cream manufacturers. The peculiarities of dextrose and its proper use in the manufacture of sweetened condensed milk are discussed in detail in Chapter X.

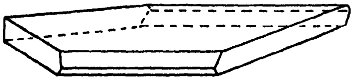

Fig. 100. Dextrose hydrate crystals

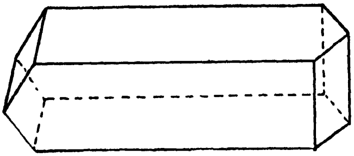

Fig. 101. Anhydrous dextrose crystals

Courtesy of Corn Products Refining Co.

Dextrose is a monosaccharide in contrast to sucrose and lactose which are di-saccharides. There are two distinct forms of dextrose, the hydrate and the anhydride.

Dextrose Hydrate ($C_6H_{12}O_6H_2O$).—The hydrate dextrose is the corn sugar of commerce, also known by the trade name Cerelose. Becke[154] places the dextrose hydrate crystal in the monoclinic system. The crystal type of dextrose hydrate that lends itself to commercial manufacture is a flat crystal, about as long as it is broad and much thinner than it is broad. The hydrated Cerelose has a reducing sugar content figured as dextrose on a dry basis of 99.9 per cent. It contains from 7 to 9 per cent water, most of which is in the form of water of crystallization.

Anhydrous Dextrose ($C_6H_{12}O_6$).—The crystal of the anhydrous dextrose, also known by the trade name anyhdrous Cerelose, belongs to the rhombic system, and appears as elongated prisms. It is a purer commercial form than the hydrate and its moisture content is less than 0.5 per cent.

The solubility of dextrose as compared with sucrose is given in Table 12. The crystallization of dextrose is materially retarded by the presence of colloids. As explained in Chapter X, the use of dextrose in sweetened condensed milk, when dissolved in the milk during forewarming, tends to intensify discoloration and thickening of the finished product with age. The relatively low solubility of dextrose at low temperatures invites mass crystallization when present in sweetened condensed milk in highly concentrated form. These several defects may be readily overcome by the proper adjustment of the method of manufacture and of the dextrose-in-water concentration in the finished product.

The preserving power of dextrose as compared with sucrose has not as yet been conclusively determined. On the basis of its higher osmotic pressure dextrose should exceed the preserving power of sucrose, but comparative tests showing the relative preservative power of sucrose and dextrose in sweetened condensed milk are too limited in scope and too indefinite in results to justify conclusions. The available evidence suggests that the difference in preservative power is slightly in favor of dextrose. This advantage is offset, however, by the fact that dextrose cannot be used in as high concentrations as sucrose on account of its lower solubility and the danger of mass crystallization.

Citric Acid.—Citric acid is a normal constituent of milk. Its formula is $H_3C_6H_5O_7 \,.\, H_2O$. The citric acid content of milk is variably given at .1 to .4 per cent. Green feeds increase it while the development of lactic acid in milk by bacteria tends to destroy it. It is thought to be present in milk largely in combination with calcium, magnesium and potassium, forming salts with these bases. Sommer and Hart[83] demonstrated that the citric acid together with the phosphates of milk plays an important role in the establishment of the calcium-casein balance which in turn controls the stability of the casein toward heat. When there is an excess of calcium and there is not sufficient citrate and phosphate to compete with the casein to lower its calcium content to the optimum calcium-casein balance, the casein becomes very unstable toward heat. The addition to such milk of enough citrate or phosphate to balance the excess calcium stabilizes the casein with respect to heat coagulation. For detailed discussion see Chapters XV and XVI.

In evaporated milk upon aging the citric acid is prone to precipitate as tricalcium citrate, forming a grainy whitish sediment in the bottom of the tin. The cause and prevention of this defect is discussed in Chapter XXVI.

THE COLOR OF MILK

Normal cow's milk varies in color from almost chalk white to ivory and light cream. The opaque whiteness is due to the dispersion of exceedingly minute particles of casein. The color other than white is due to the presence of two separate and distinct types of pigments, lactochrome and carotin.

Lactochrome is a water-soluble pigment that gives the milk whey its yellow color. The quantity present varies considerably with breed of cows. The study of the color of whey from 43 cows of four different breeds by Palmer and Cooledge[155] revealed the following results:

Breed	Units of Yellow
Ayrshire	4.78
Jersey	3.49
Holstein	2.41
Short Horn	2.15

The source of lactochrome has not been fully determined, but the results of its study suggest a close relationship between the yellow lactochrome of milk whey and the yellow pigment urochrome of urine. Available data suggest that while it may not be derived directly from the feed of the cow, indications point to some relation between feed and lactochrome content of the milk. It is believed to be a protein derivative. Lactochrome is not confined to cow's milk alone. It has been found in the whey of ewe's milk and human milk as well.

Carotin belongs to a group of pigments called carotinoids that are fat-soluble. These pigments have been studied by Palmer and Eckles[156] and their findings have been comprehensively reviewed by Palmer.[157] They are derived from the green leaves of plants. In the milk they are associated with the milk fat to which they are directly transferred from the feed through the blood stream. It is the presence of carotinoids that gives the butterfat its yellow color. Since green feeds are richest in carotinoids, the butterfat produced in spring and early summer is colored more deeply yellow than winter butterfat. The ability to incorporate carotin in the butterfat varies materially with the breed. When on green feed the Jerseys and Guernseys produce a much more highly colored butterfat than the Ayrshires and Holsteins. The cow appears to be the only mammal supplying milk for the human family whose fat contains these fat-soluble pigments in appreciable amounts. According to Palmer and Eckles, human milk frequently also shows shades of yellow.

The presence of these pigments lends normal milk and condensed milk a rich creamy color which, because of the influence of breed and feed, will vary somewhat in intensity of shade with locality and season of year.

Color of Condensed Milk.—Condensed milk usually, though not always, is darker in color than the fluid milk from which it is made. To a limited extent this is undoubtedly due to the greater concentration of the pigments in the condensed product and partly to a change in the nature of dispersion of its colloidal constituents. This intensified natural coloration lends the finished product an attractive appearance of richness.

Much of the condensed milk on the market, however, has a distinctly darker coloration than can be attributed to the above causes alone. Sweetened condensed milk may show a definitely brown color and this is usually the case with products that have been stored for a considerable period at room temperature or above. Evaporated milk that has been on the market for some time at similar temperatures also shows an unnatural brownish discoloration. In case of unduly prolonged exposure to sterilizing heat, or the addition of considerable bicarbonate of soda used as a stabilizer in manufacture, the evaporated milk has a dark color when it comes from the sterilizer. The darkening of color of both sweetened condensed and evaporated milk also occurs when "rerunning" milk of previous batches with the fresh milk.

The above color defects have been observed and combatted by the manufacturer from the very beginning of the industry. Formerly the discoloration was attributed to caramelization of the sugar of milk in the presence of the heat employed in manufacture, and in the case of sweetened condensed milk to caramelization of both lactose and sucrose. This conception of the causes of darkening in color has persisted in spite of the fact that there have been available for some time experimental evidences suggesting causes other than caramelization.

More recent study of this problem has shown that the temperatures employed in manufacture of all types of condsensed milk are seldom, if ever, sufficiently high to induce caramelization of either lactose or sucrose, as the direct result of oxidation and that the true cause must lie elsewhere.

The results of investigations by Undransky, Keppe-Segler, Samneli, Maillard, Gortner and Blisch, which are reviewed by Allen,[158] and the work of Wright.[159] and Ramsey, Tracy and Ruehe[46] have revealed that when sugar, especially lactose and dextrose, is heated in the presence of proteins, interaction takes place that yields sugar-protein condensation products accompanied by a darkening of color. These reactions appear to have to do with the formation of certain sugar-amino-acid complexes.

This chemical interaction between the sugar and amino-acid groups applies especially in the case of reducing sugars, such as lactose and dextrose. Sucrose as such does not enter into these reactions to the same extent because of the stable linkage that exists in the sucrose molecule between the aldehyde group of dextrose and the ketone group of fructose and levulose, unless the sucrose has suffered partial inversion, such as may occur in the presence of relatively high acidity or as the result of enzymic action.

It appears, therefore, that the discoloration of both sweetened condensed milk and evaporated milk is due to a lactose-protein reaction fundamentally induced in the presence of the high temperatures employed in manufacture. Prolonged exposure to heat is more conducive to discoloration than higher temperatures for short duration. While the reactions responsible for the brown discoloration apparently require the presence of heat such as the milk is subjected to in manufacture, the darkening is normally not instantaneous, such as would be the case with caramelization. It appears to be progressive. The darkening progresses with the age of the product and it depends on the temperature of storage. Below room temperature it develops very slowly and below about 45° F. there is no discoloration visible to the eye for many months. At room temperature and above, however, pronounced darkening occurs, the rapidity and intensity of the color change increasing as the temperature rises.

Haradine[49] who studied the color of sweetened condensed milk spectrometrically found that the temperature of forewarming had practically no influence on the color change in storage, that at a storage temperature below 68° F. the change was very slow, but that above 68° F. and especially from 80 to 100° F.

the brown discoloration progressed very rapidly. At 100° F. the product had a dark brown color within 30 days. He further found a marked hastening of the color change when 25% or more of the sucrose was substituted with invert syrup, while less than 25% substitution caused the change to progress at practically the same rate as in the absence of invert syrup. The results of Ramsey, Tracy and Ruehe on the other hand indicated that even 75% substitution with dextrose did not darken the milk in cool storage when the sugar and the milk were forewarmed separately and the sugar syrup was added toward the end of the condensing process.

The intense darkening of evaporated milk in storage above room temperature with which the manufacturer is familiar, likewise may be attributable to the result of interaction between lactose and milk proteins induced by the high temperatures used in forewarming and in sterilizing. It is possible, however, that the darkening of this product during prolonged sterilization may be attributable, in part at least, to oxygen absorption and caramelization.

Webb and Holm[120] studied the color of evaporated milk by the use of the Munsell color system which determines the quantity of the three attributes of color; namely, hue, chroma and brilliance. They report that "the effect of heat, whether encountered during forewarming, sterilization or storage, was found to produce important changes in color. An increase in heat produced an increase in color, the change being catalytic in nature, dependent probably upon the production of substances in the solution which increase the susceptibility of the lactose to caramelizing."

When forewarming at a temperature of 95° C. (203° F.) for the usual short periods applied in commercial manufacture, the finished product showed no appreciable change in color, but forewarming for a prolonged period, such as 30 minutes or longer, caused a very noticeable increase in color after sterilization.

The temperature and time of sterilization were found to be the most important factors influencing the color of evaporated milk. It was noteworthy that the pH decreased and the color darkened with an increase in both time and temperature of heating.

Homogenizing caused a slight reduction in color. This may be attributable to the usual optical effect caused by a marked diminution of particle size. Homogenization reduces the size of the fat globules and possibly of the casein particles as well.

The same investigators stored evaporated milk samples of one and the same batch at temperatures ranging from 5 to 37° C. (41 to 98.6° F.) for three months. No change in color occurred at 41° F., but at all other temperatures progressive darkening was noted. The higher the temperature the more rapid the change in color. Their results agree with commercial experience. They hold that a color change of a different nature from that observed during sterilization was taking place.

CHAPTER XXIV

BACTERIA, ENZYMES, VITAMINS AND DIGESTIBILITY OF CONCENTRATED MILKS

BACTERIA

From the point of view of freedom from pathogenic and other harmful micro-organisms, most forms of condensed milk are equal, if not superior, to the average market milk. In the first place, the manufacture of a marketable condensed milk makes essential eternal vigilance in the control of the quality of the fresh milk. It is safe to state that in no milk plants does the quality of the fresh milk accepted, receive more careful attention and average higher than in the milk condensery. The foundation of the condensed product, the fresh milk, therefore, is of a relatively high standard of purity.

Again, the temperatures to which the milk is subjected in the process of manufacture are usually sufficiently high to destroy the germs of practically all milk-borne diseases; so that, unless the condensed milk becomes infected with pathogenic germs after condensing and before the tin cans are hermetically sealed, practically all danger from disease germs is eliminated.

In the case of evaporated milk, as now manufactured, and sterilized in hermetically sealed tins, in accordance with the standard processes herein described, sound tins of this product may reasonably be expected to be free from all forms of germ life. This is in fact the case in the great majority of cases, as is evidenced by a multitude of bacteriological analyses of evaporated milk on record. By the term "sound" tins is meant tins which, when picked up on the market, or in the factory after the usual period of incubation, show no leaks, no bulging at the ends, respond to shaking with the characteristic sound of a homogeneous liquid, and upon opening show a normal acidity. In most cases where plate counts reveal the presence of living germs in the evaporated milk, the cause either lies in accidental contamination due to faulty technique in sampling, or in the fact that the tin fails to meet all the requirements of the above definition for "sound" tins, i.e., the tins showing germ life are usually not sound tins, they are defective or their contents are defective. See "Defective Evaporated Milk," Chapter XXVI.

Exceptions to the above assertion do occur occasionally, however. Instances have been found where apparently truly sound tins did contain some living organisms. This unusual phenomenon may occur when the particular type or species of micro-organisms that survived sterilization develops very slowly and is capable of bringing about visible changes only after an extended period of time. Such cans may even pass into consumptive channels without showing abnormal symptoms and therefore, without being detected.

Plain condensed milk (unsweetened), such as is sold in bulk, is not sterile. When fresh, its germ content is usually relatively low (below 100,000 per gram) in spite of its high concentration (3½ to 4:1). It is highly perishable, however. Unless held under refrigeration it will soon sour or undergo other bacterial deterioration.

Sweetened condensed milk is not sterile. Sound tins usually contain diverse species of bacteria, and almost invariably some yeast and mold. Gaseous fermentation in this product is usually caused by yeast capable of thriving in highly concentrated sugar solutions, as shown by Hammer and Cordes,[143] Hunziker,[144] Savage and Hunwicke.[161] Rice and Downs[162] showed that the thickening of sweetened condensed milk with age was due in some cases to bacterial activity. They found a coccus species that was capable of thickening the milk. The formation of "buttons" as shown by Rogers, Dahlberg and Evans[163] is the result of mold growth.

While the temperatures used in preheating and condensing sweetened condensed milk are not sufficiently high to render this product completely sterile, the reduction of bacteria is very considerable during these processes. When the milk comes from the pan its germ content is approximately 0.1 per cent of the total bacteria of the raw milk, provided a high standard of cleanliness of equipment and of sanitary operation prevails in the factory.

Between the vacuum pan and the hermetically sealed tins, however, there are obvious channels of recontamination. The extent of bacterial contamination at this stage of the process is determined largely by the system of handling the condensed milk during cooling, storing, filling and sealing, and by the sanitary condition of all equipment and conduits that come in contact with the milk, and the relative sterility of the empty tins.

On account of its high sucrose content sweetened condensed milk is not a good medium for the growth of most of the species of bacteria and yeast ordinarily present in milk. For this reason most of these bacteria do not thrive well and their growth is almost completely inhibited in this product. Bacterial counts of sweetened condensed milk tins picked up at random on the market show that in the case of milk of good quality the number of germs is confined to but a few hundred per gram.

There are some species of bacteria, yeast and mold, however, that are sucrose-phylic, they thrive in highly concentrated sugar solutions and when present in sweetened condensed milk they multiply rapidly under favorable conditions of concentration, temperature and air supply. The number of bacteria found in condensed milk so contaminated varies with age and storage temperature and may run into many millions per gram. Their presence is responsible for such defects as thickened milk and stale flavor, blown tins, the appearance of buttons, etc., see also "Defective Sweetened Condensed Milk," Chapter XXV.

ENZYMES

Enzymes are chemical substances produced by living plant and animal cells. The chemical structure of enzymes is unknown at present, they are known by their action on substances or substrate. They are capable of accelerating chemical changes already in progress without being themselves altered or becoming a part of the products formed. In this respect they resemble a true catalyst. Extremely minute quantities are capable of bringing about profound and far-reaching changes.

Unlike micro-organisms, enzymes do not depend in their functions on food, moisture and air supply. They do not reproduce themselves, they do not increase nor become invigorated. Their action is independent of the living cells, colloidal in nature, nondializable and they do not form a true solution. The action is influenced by the acidity or alkalinity of the medium and by heat, however; they are inactivated when the temperature is above that for optimum activity.

It is now conceded by the foremost authorities that most of the changes attributed to the direct action of micro-organisms are the results of enzymes secreted by them.

Some of the enzymes of milk appear to be inherent in the lacteal fluid. They are present when the milk is drawn. Others are present because they have been secreted by certain species of micro-organisms contained in the milk. The milk enzymes are of special importance in connection with the manufacture of dairy products such as condensed and evaporated milks, because of their ability to bring about changes that affect the keeping quality of these products. Their presence in concentrated milks invites progressive deterioration with age. For dependable keeping quality their destruction by the process of manufacture is essential.

The more important enzymes of milk are the proteolytic enzymes, of which the enzyme galactase[1] is a definitely known representative; the fat-splitting enzymes or lipases; the oxidizing enzymes peroxidase and catalase; and the enzyme reductase, the presence of which is determined by its action on certain color compounds, and particularly by its ability to bleach methylene blue.

All of these milk enzymes are either destroyed or rendered inactive by forewarming the milk at temperatures of 75° C. (167° F.) or above for not less than ten minutes. Forewarming at lower temperatures tends to deprive sweetened condensed milk of dependable keeping quality and to cause a type of age deterioration that suggests slow but progressive protein decomposition brought about by proteolytic enzymes. Abnormally low forewarming temperatures (below 150° F.) also invite the development of rancidity in sweetened condensed milk, due to the survival and activity of the fat-splitting enzyme lipase (See Chapter XXV). In the case of evaporated milk the possibility of age deterioration due to enzymic action is precluded because of the inevitable destruction of all enzymes by the heat treatment in the sterilizer.

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[1] According to the present system of nomenclature, the term *Proteinase* would better express the properties of this enzyme.

Enzymes play an important role in the preparation, fermentation and digestion of foods in the metabolism of the living organism. The value of the milk enzymes as an aid to digestion is uncertain. If their function in the food metabolism is important, then the concentrated milks fall short in this particular respect, as compared with fluid raw milk or fluid milk that has been subjected to low-temperature pasteurization.

VITAMINS

Discoveries by eminent nutrition experts, have revealed and conclusively demonstrated the presence of vitamins, or chemically unknown substances of food origin, that are essential for the normal performance of the function of animal life. Extensive feeding experiments have shown, that before complete growth can occur in a young animal, or for prolonged maintenance, or for the prevention of certain diseases, the diet, besides being adequate as regards its content of proteins, carbohydrates, fats and mineral salts, must contain certain, at present unidentified accessory substances, generally called vitamins.

Vitamin A (The Anti-Ophthalmic Vitamin.)—The absence of this substance in the diet retards and stunts growth and leads to the disease of xerophthalmia (an eye disease culminating in blindness). This fat-soluble vitamin is present abundantly in a limited list of foods, namely, in milk fat, egg fat, cod liver oil, halibut liver oil, the fats of the vital organs, in the leaves of certain vegetables, in some of the tubers and certain fruits. It is not contained in ordinary animal fats such as lard, nor in any of the vegetable fats. This vitamin is sensitive to oxidizing agencies and is claimed to be readily destroyed by oxidative processes, but it is resistant to heat.

Feeding experiments to determine how vitamin A is affected by heating showed that autoclaving at 10 to 15 pounds of pressure had no effect on it. This would indicate that the condensing and sterilizing process do not destroy vitamin A and that it retains its full vitality in both sweetened condensed milk and in evaporated milk.

On the other hand, skim condensed milk is not a satisfactory food for the growing young. It lacks the indispensable fat-soluble accessory and unless supplemented by egg yolk, cod liver oil, butter or other foods rich in vitamin A, its consumption by the young in the place of whole milk, or in the place of condensed milk made from whole milk, will prove disastrous to the growth and well-being of those who are restricted to such a diet.

Vitamin B (The Anti-Neuritic and Anti-Pellagric Vitamins.)—Vitamin B was first thought to be a single vitamin, but later it was found to consist of two distinct substances which were for a time known as B_1 and B_2. In America the designation B_2 was changed to Vitamin G, so named in honor of Dr. Goldberger of the United States Public Health Service, who discovered that Vitamins B and G are two distinct substances. Vitamins B and G stimulate appetite, aid digestion and assist in a general feeling of well-being. Complete absence of vitamin B leads to neuritic disturbances such as the disease of beri beri, or general paralysis. Absence of vitamin G causes a skin disease known as pellagra.

Vitamins B and G are water-soluble substances, present in a variety of foods, and constitute an inherent part of the non-fat portion of milk (skimmilk). Milk and green, leafy vegetables appear to be much better sources of vitamin G than of vitamin B. Likewise vitamin G is more heat resistant than vitamin B. While experimental results on this point are too limited for definite conclusions, indications suggest that the heat employed in the manufacture of condensed and evaporated milk is more destructive to vitamin B than to G, the latter retaining practically its full strength while vitamin B appears to be diminished somewhat by the heat treatment employed in manufacture.

Vitamin C (The Anti-Scorbutic Vitamin.)—The absence of this vitamin substance in the diet causes the development of scurvy and similar scorbutic diseases and skin diseases. The anti-scorbutic vitamin appears to be present in many foods, it is a water-soluble vitamin, and it is present also in raw milk.

Vitamin C is readily destroyed by heat, especially in the presence of air or metallic salts such as the salts of copper.

Experimental results and conclusions of different investigators are somewhat at variance on this subject. Some authors maintain that it is destroyed at pasteurizing temperatures, while others hold that higher temperatures are required to inactivate it. Hess and Fish,[164] and later Hess, [165] reported a mild outbreak of infantile scurvy caused by the use, for several months, of a diet of cow's milk previously pasteurized at 63° C. (145° F.) for 30 minutes. The scorbutic symptoms disappeared on adding orange juice, lemon juice, leaves of green vegetables, etc., to the diet, or on the substitution of raw milk for the pasteurized milk.

Hart, Steenbock and Smith[166] found that milk sterilized at 120° C. (248° F.) for 10 minutes had lost its anti-scorbutic powers when used in quantities equivalent to an amount of raw milk which would prevent scurvy in guinea pigs on a diet of rolled oats and dried hay. These investigators further report that the several brands of unsweetened condensed milk (meaning evaporated milk) with which they worked, had also lost their anti-scorbutic properties.

Hess and Weinstock[167] point out that the presence of even small amounts of copper in the milk greatly hastens the destruction of this vitamin, due to catalytic action, and that the destructive oxidative action of the air while heating, also intensifies the damage done by heat. Their conclusions are: "Were it not for the fact that condensing is carried out in vacuum or partial vacuum, condensed milk would be deprived of all its anti-scorbutic vitamin. As the result, however, of the exclusion of air in the course of the heating process, such milk may retain the greater part of its anti-scorbutic potency."

There is need here of consideration of the fact that the temperature used in preheating and in sterilizing, which processes are not carried out in vacuum, are far higher than those of the process of condensing proper. The fact that the milk is condensed in vacuo does not protect its vitamin properties against the much more severe action of the higher temperatures used in preheating and sterilizing.

On the basis of our present knowledge of the effect of heat on the vitality of vitamin C, it appears reasonable to conclude that evaporated milk cannot be recommended as an exclusive milk diet for babies and children. If evaporated milk must be used for infant feeding, some anti-scorbutic supplementary food, such as orange juice, should be fed in conjunction with the exclusive use of evaporated milk or similar heated milk product.

To what extent the anti-scorbutic properties of milk are preserved or destroyed in the manufacture of sweetened condensed milk, has not as yet been experimentally demonstrated. This product is not exposed to sterilizing temperatures and yet it is heated to near the boiling point. The safer course to follow here, too, if sweetened condensed milk must take the place of normal raw or pasteurized milk, is to feed it in conjunction with a known anti-scorbutic supplementary food, such as orange juice.

Vitamin D (The Anti-Rachitic Vitamin.)—Vitamin D is associated with that part of the diet that functions in the bone or skeletal development. Its presence in the diet increases the retention in the body of calcium and phosphorus, the minerals so essential in the normal building-up of the bone structure. The absence of vitamin D in the diet tends to develop the disease called rickets. This disease has to do with weakness of the bony structure, enlargement of the ends of the bones and their bending due to lack of resistance to the body weight. It is the cause of bone distortion and deformity. Some of the more common outward symptoms are bow legs, knock knees, enlarged joints, flat chest, abnormal conformation of skull, defective teeth, general weakness of the entire body, and subnormal vitality. It is a disease of infancy and early childhood.

According to McCollum,[168] vitamin D appears to be closely associated with vitamin A being present most abundantly in cod liver oil and also in milk fat. Its presence alone, however, is not sufficient to protect against rickets. Its protective influence depends on the presence of a sufficient amount of and the proper balance between the calcium and phosphorus. It has been found to be more stable than vitamin A and there appears to be a close relation between sunlight, vitamin D and rickets.

The vitamin D content of milk varies greatly with that of the feed of the cow and with the access of the cow to sunlight. Green feeds and properly cured (kiln dried) leafy feeds increase the vitamin D of milk, while dry feeds and ordinary field-cured hay diminish it. Experimental results as well as limited experience on a commercial scale have demonstrated that the vitamin D strength of milk may be successfully augmented by the feeding of irradiated yeast to the cow, or by direct irradiation of the milk, or by adding to the milk a small quantity of irradiated ergosterol (viosterol), or natural concentrates of this vitamin in the form of concentrates of cod liver oil or halibut liver oil.

According to recent observations and findings of the medical profession, the disease of rickets is today one of the most widely prevalent diseases encountered among the children of certain strata of our population. This is attributed to a generally recognized deficiency of vitamin D in the normal mode of living in the temperate zone, resulting in a really serious amount of mild rickets in children and in lowered resistance to infection and to teeth decay in many children and adults. This situation prevails because we do not get sufficient Vitamin D through sunshine by reason of the changed and unnatural conditions of our modern civilization with its clothing, indoor living habits, smoke and dust. Added to these conditions is the fact that Vitamin D is not available in protective amounts in the normal diet. Even milk is not an adequate source of this vitamin.

Milk, however, contains the calcium and phosphorus necessary in the diet of infants and children and it likewise contains the pro-vitamin ergosterol which needs only exposure to ultraviolet light to activate it into Vitamin D. On the basis of the now available experimental results it is believed, therefore, that, by irradiation of the milk, a protective amount of Vitamin D can be created, and that milk so irradiated constitutes a dependable preventive of rickets. It has been further determined that it is physically impossible to drink enough milk to receive an excessive amount of this vitamin.

The process of irradiating any food product or pharmaceutical product to increase Vitamin D potency was patented by its inventor, Dr. Harry Steenbock, U. S. Patent No. 1,680,818. The patent was assigned to and is controlled by the Wisconsin Alumni Research Foundation, Madison, Wisconsin. The process of irradiating milk and milk products is now available to the dairy industry upon application for license to use the process. For description of equipment and process, see Chapter XII under the caption, "Irradiation of Evaporated Milk."

The fact that evaporated milk, after irradiation, is subjected to sterilizing heat (240 to 245° F. for 15 to 20 minutes) and that the Vitamin D potency of the sterilized product has been found undiminished, suggests that the temperatures employed in the manufacture of all concentrated milks do not impair the Vitamin D strength of these products.

Vitamin E (The Anti-Sterility Vitamin.)—This vitamin is essential for reproduction. Its continued absence in the diet leads to sterility. Its chemical and physical properties are similar to those of vitamins A and D, but it differs from them in its distribution in nature. It is practically absent from cod liver oil, but present in vegetable oils. The oil of the wheat embryo is one of the richest sources of vitamin E. It is abundantly present also in lettuce. Milk fat contains it to a limited extent. No data are available as yet (1934) regarding its resistance to heat. However, the similarity of its physical properties to those of vitamins A and D suggest that vitamin E may also be heat-resistant and that it may be present in undiminished strength in the concentrated milk.

DIGESTIBILITY

Available experimental data fail to provide conclusive facts regarding the relative digestibility of raw and concentrated milks. On the basis of our present limited knowledge it appears reasonable to conclude that, as far as the digestibility of its inherent ingredients is concerned, the concentrated product, when consumed in properly diluted form, varies but little, if any, from raw milk.

The milk fat is not known to have undergone any chemical change, and the magnified state of dispersion of the fat globules in the condensed and evaporated milk should help rather than hinder its digestion. The lactose, though it may have yielded to slight caramelization, or to interaction with the proteins of milk, or both, is not known to have sacrificed its natural ease of digestion and assimilation. Of the chief proteins of milk, the albumin and the casein, the albumin is coagulated in large part by the heat of manufacture. It is well known that the heat coagulation of egg albumin does not diminish its digestibility. This suggests a similar situation in the case of the milk albumin contained in the concentrated product. The casein molecule in the heated milk surrenders some of its soluble calcium and reacts no longer toward rennet in the same manner as the casein of raw milk. Instead of forming a solid coagulum or clot in the presence of rennin, it yields a finely flocculent precipitate which promises to be far more accessible to the digestive juices of the stomach than the casein clot of raw milk. Some of the mineral constituents of milk, particularly the calcium and phosphorus, are precipitated by the heat of manufacture. This fact has led to the popular assumption that these minerals either have been lost in the process, or have become much less digestible. There is no experimental evidence to show that in this precipitated form they are less digestible, and those familiar with the process of manufacture know that the possibility of mechanical loss of precipitated milk minerals is exceedingly remote. That no appreciable loss of ash constituents occurs between the milk receiving platform and the sealed tin is further emphasized by the fact that analyses of the concentrated product invariably show an ash content equivalent to that of the fluid milk times the ratio of concentration.

As far as the major chemical constituents of the milk are concerned, therefore, there is no tangible evidence that the concentrated product is less digestible than the raw milk from which it is made. The absence in condensed and evaporated milks of ferments, such as enzymes which are rendered inactive by the heat employed in manufacture and the activity of which may assist in digestion, appears to be the only known, important deficiency of the concentrated milk from the point of view of digestibility.

In the case of sweetened condensed milk, however, the nutritive ratio of the normal milk is decidedly disturbed by the presence of large quantities of sucrose. Even when diluted to far beyond the composition of normal fluid milk, the per cent of cane sugar is still high, causing the nutritive ratio of such milk to be abnormally wide and unbalanced. The carbohydrates are present far in excess of the protein, fat and ash. If fed to infants exclusively and for a prolonged period of time, the growing organism is bound to suffer from malnutrition and at the expense of muscular development. If sweetened condensed milk is utilized for infant feeding it is advisable, therefore, to modify its composition by properly supplementing it with easily digestible supplemental food products, such as barley water, etc., that will more nearly balance the ration.

Perhaps the most trustworthy judgment regarding the digestibility of condensed and evaporated milk is found in the experience of physicians and dietitians in whose practice the canned product has served as a substitute for fluid milk at times and under conditions that precluded the availability of a safe milk other than canned milk.

Deeks,[169] in discussing the problems of infant feeding in the tropics, states that "the best available source in all districts for the feeding of infants is sweetened condensed milk, evaporated milk, and powdered milk." As general manager of the Medical Department of the United Fruit Company, Dr. Deeks found both sweetened condensed milk and evaporated milk satisfactory substitutes for raw milk as baby food, when properly modified, where a good quality of fresh milk is not available. His formulas for baby feeding in the Tropics are given below:

Table 39—Modified Milk for Baby Food.

Made from Sweetened Condensed and Evaporated Milk

Age of Infant	Daily Amount Necessary	Sweetened Condensed Milk	Evaporated Milk	Water or (after fourth month) Barley Water	Amount of Each Feeding	Interval of Feeding	Number of Feedings Daily
	Ounces	Teaspoonfuls	Teaspoonfuls	Ounces	Ounces	Hours	
1 day........	1– 4	....	....	1– 4	¼–½	2–4	4– 8
2 days.......	8	1	3	7½	½–1	2	6– 8
3 days.......	10	1½	4½	9½	½–1	2	8–10
4 days.......	11	2	6	10	1–1½	2	10
5 days.......	13	3	9	11	1–1½	2	10
6 days.......	14	4	12	12	1½	2	8-10
7 days.......	15	5	15	12	1½–2	2	8
1 to 4 weeks..	15–25	6–10	18–30	12–20	2 –3½	2	8
		Ounces	Ounces				
1 to 3 months.	25–35	1½–2¼	4½–6¾	20–27	4 – 5	2½	6– 7
3 to 6 months.	40–48	2½–3	7½–9	30	6 – 8	3	6
6 to 12 months	48	3	9	30–36	8 –10	3–4	5– 6

Blackham[170] points out that "there is no trustworthy evidence that artificial feeding at any period with fresh cow's milk is any better than feeding with heated cow's milk. On the contrary reliable opinion on the whole favors heated milk against

Table 40—Modified Milk for Baby Food.

Made from Evaporated Milk with Added Sugar

Age of Infant	Daily Amount Necessary	Evaporated Milk	Water or (after fourth month) Barley Water	Milk Sugar CaneSugar or Dextrimaltose	Amount Each Feeding	Interval of Feeding	Number of Feedings Daily
	Ounces	Ounces	Ounces	Teaspoonfuls	Ounces	Hours	
1 day........	1–4	....	4	....	¼– ½	2- 4	4– 8
2 days.......	8	4*	7½	3	½–1	2	6– 8
3 days.......	10	6*	9¼	3½	½–1	2	8–10
4 days.......	11	1	10	4	1–1½	2	10
5 days.......	13	1½	11½	5	1–1½	2	10
6 days.......	14	2	12	5	1½	2	8–10
7 days.......	15	2½	12½	5	1½–2	2	8
1 to 4 weeks..	16–25	3– 5	12–20	5– 6	2 –3½	2½	8
1 to 3 months.	25–36	6– 9	18–27	7– 7½	4 –5	2½	6– 7
3 to 6 months.	40–50	10–12½	30	9	6 –8	3	6
6 to 12 months	50	12½	30–37½	9–12	8 –10	3–4	5– 6

*Teaspoonfuls.

fresh, and the two French authorities I have quoted above (referring to the two great French physicians Aviragnet and Dorlencourt) pointed out that heated cow's milk is much less toxic than fresh. Professor Marfan of Paris says, "Cow's milk is better raw than cooked for calves and better cooked than raw for infants."

PART V

Condensed Milk Defects, Their Causes and Preventions

CHAPTER XXV

DEFECTIVE SWEETENED CONDENSED MILK

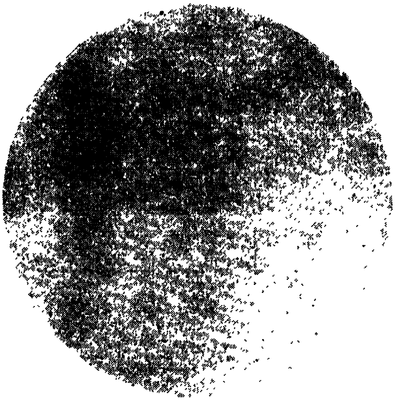
Sweetened condensed milk is subject to the development of numerous defects that may materially depreciate, if not completely destroy, its market value. The changes underlying these defects may be due to reactions of biological, physical or chemical nature, or they may be due to the combined action of several agencies. The most common and most important defects encountered are sandiness, sediment, thickening, lumpiness, bloats and brown discoloration. Other defects, which are of less common occurrence, are rancid flavor, tallowy flavor, metallic flavor, fat separation.

SANDY SWEETENED CONDENSED MILK

General Description.—The product is permeated with sugar crystals of a size sufficiently large to rob the milk of the desired smooth and velvety texture that is characteristic of sweetened condensed milk of superior quality. It is physically coarse, feels rough to the tongue, and "grits" between the teeth. While this defect does not impair its wholesomeness, it denotes faulty workmanship and it is objected to by the trade and the consumer.

As shown by Sato,[171, 172] several of the constituents of milk may and do form crystals in sweetened condensed milk. This investigator isolated crystals of lactose, sucrose, calcium phosphate, calcium citrate, etc. from the sediment found in the condensed milk. It was definitely established, however, many years before Sato's work, both microscopically and chemically, that sandiness in sweetened condensed milk is caused largely by the crystals of sugar of milk.

Milk sugar invariably crystallizes during the cooling process, due to its relatively low solubility and its high concentration in sweetened condensed milk. The appearance of sandiness depends on the size of the crystals. The secret of preventing sandiness and of insuring a smooth product lies in so organizing the process of cooling as to bring about the formation of so large a number of small individual crystal centers that the state of supersaturation is reduced to a state of saturation, thereby making conditions unfavorable for the subsequent development and growth of large crystal aggregates.



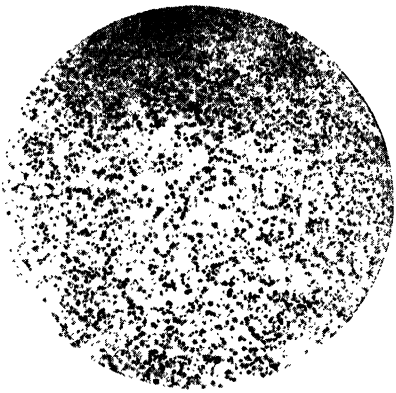


Fig. 102. Smooth sweetened condensed milk

Fig. 103. Sandy sweetened condensed milk

Macro-photographs under glass plate

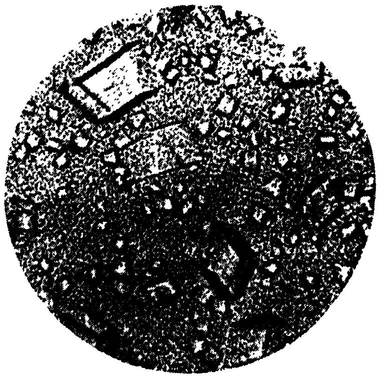


Fig. 104. Smooth sweetened condensed milk

Fig. 105. Sandy sweetened condensed milk

Microphotographs, mag. X 130

The science and theory of the solubility of milk sugar and the behavior of saturated and supersaturated solutions of milk sugar are discussed in detail in Chapter XXIII on the "Chemical Composition and Physical Properties of Condensed Milk." A thorough understanding of these fundamentals will prove helpful in the successful adjustment of the cooling process under diverse conditions.

Smoothness of Condensed Milk Depends on Size of Lactose Crystals Formed.—In order for sweetened condensed milk to be of smooth and velvety texture, its lactose crystals must be of very small size. It has been found that these crystals should measure not more than 10 microns (.01 mm.) in length. When the great majority of the crystals present measure between 10 and 12 microns (.01 and .012 mm.) long the milk is still of good texture but leans toward a slightly pasty character; between 12 and 15 microns the milk takes on a somewhat mealy character, though not as yet seriously objectionable; between 15 and 30 microns the milk is very mealy to slightly sandy; and beyond 30 microns (.03 mm.) the milk becomes objectionably sandy.

In order to produce a smooth and velvety product, therefore, the size of the great majority of the crystals should be limited to a length of not to exceed approximately 10 microns (.01 mm.)

Size of Crystals is Controlled by the Number of Crystal Centers Produced.—If, during the cooling process, a relatively small number of crystal centers are formed, these crystal centers are capable of growing into large aggregates and large crystals will inevitably have developed after cooling by the time all the lactose in excess of saturation has crystallized out. Under these conditions the product will be sandy and rough.

This may be avoided by so organizing the process of cooling, as to encourage the formation of so large a number of small crystal centers, that there is not enough lactose present in excess of saturation to enable them to grow into large crystals.

Even slight growth of each unit of this great multitude of crystal centers will quickly exhaust the supply of excess lactose, rapidly reducing the unstable state of supersaturation to the stable state of saturation, when all further crystal development ceases. Under these conditions the product will be permanently smooth and free from sandiness.

The number of crystals required to produce a milk in which the great majority of crystals are no larger than 10 microns varies with the lactose-in-water ratio of the condensed milk, that is, it depends on the degree of supersaturation. Under average conditions the presence in milk of approximately 300,000 crystals per cubic millimeter may be considered sufficient to limit the size of the great majority of crystals to about 10 microns and to produce a smooth milk. In the case of a very high degree of lactose supersaturation, such as where the lactose-in-water ratio exceeds 50 parts of lactose for every 100 parts of water, the number of crystals per cubic millimeter of condensed milk may need to be considerably greater, while in milk with a relatively low lactose-in-water concentration, such as 40 or less parts of lactose for every 100 parts of water, the number of crystals necessary to produce smooth milk may be considerably less (about 230,000 to 250,000 per cubic millimeter).

Mass Crystallization Is Enhanced by a Forced Crystallization Period in the Cooling Process.—The formation of the desired multitude of small crystal centers may best be brought about by making provision in the cooling process for a period of forced crystallization, taking advantage of our knowledge of the science of lactose solubility as explained in Chapter XXIII. The forced crystallization period, in order to produce the maximum number of small crystal centers in the shortest time, must fall within a temperature area in the cooling process that represents a high state of supersaturation, consistent with minimum viscosity. Supersaturation increases the velocity of crystallization, while viscosity decreases the speed of crystal formation because it hinders the diffusion of the supply of the lactose. Supersaturation increases with a lowering of the temperature, but the drop in temperature also increases the viscosity.

While, from the standpoint of high supersaturation, the labile area (see Fig. 48), which is the temperature area below the supersolubility curve, would produce maximum velocity of crystallization, the greatly increased viscosity of the condensed milk at the temperature of the labile area diminishes the rapidity of crystal formation. It appears, therefore, that the lower section of the meta-stable area, or a somewhat narrow range of temperature area immediately above the supersolubility curve, is most conducive to maximum velocity of crystal formation and to the production of the largest number of small crystal centers in the shortest time.

If the cooling process is retarded or arrested when this temperature area is reached, and the milk is subjected to vigorous agitation, it is possible to bring about such acceleration of crystallization that the multitude of small crystal centers formed, is sufficient to reduce the state of supersaturation to a state of saturation, making it impossible for these small crystals to attain enough surface growth to develop to a size that would cause them to make the milk sandy.

Mass Crystal Formation Is Enhanced by Seeding.—During this period of arrested cooling the crystallization of the lactose may be greatly accelerated by seeding the milk with milk sugar crystals. At the approach of this period of the cooling process the number of crystal centers present is as yet small and the addition of a multitude of nuclei in the form of lactose crystals hastens mass crystallization.

The seed material may be provided in the form of powdered milk sugar or sweetened condensed milk of a previous day's run. Only a very small amount of seed material is necessary. In the case of powdered milk sugar, a teaspoonful per 10-gallon can, or 4 ounces per batch of 1,000 lbs. (100 gals.) of condensed milk is sufficient. If condensed milk is used, add about 3 gals. of seed milk to a batch of 1,000 lbs. of sweetened condensed milk.

The seed material should be added to the condensed milk when it has reached the temperature of forced crystallization, i. e., at the beginning of the forced crystallization period. It should not be added to the milk at pan temperature, as that would do no good and might under some conditions enhance the formation of large crystal aggregates that would tend to yield a sandy milk.

Proper Temperature of Forced Crystallization Depends on Lactose Concentration in the Condensed Milk.—The proper temperature at which the forced crystallization period will do the most good must vary with the lactose concentration in the sweetened condensed milk. The point of sugar saturation varies with the ratio of milk sugar-to-water.

Milk of a high concentration and high percentage of total solids is low in water content. In such milk the ratio of lactose-to-water is relatively high, hence its proper temperature of forced crystallization should be relatively high. Such milk usually represents a saturated solution of lactose at or only slightly below pan temperature and supersaturation begins with the first stages of cooling. This is the case with many of the foreign brands and with American brands intended for export to countries where the requirements for percentage of milk solids (concentration) are high.

Milk of a low concentration and a medium to low percentage of total solids, is low in lactose and high in water content. In such milk the ratio of lactose-to-water is relatively low, hence its proper temperature of forced crystallization should be relatively low. This is generally the case with sweetened condensed milk of a composition conforming to the U. S. Federal Standard, which calls for 20 per cent solids not fat and 8 per cent fat.

Practical Directions for Application of Lactose Crystallization Theory to Cooling of Sweetened Condensed Milk of Varying Lactose Concentrations.—For the convenience of the operator a chart, Fig. 48, has been designed, which shows the theoretically correct temperature for the forced crystallization period in the cooling of sweetened condensed milk of varying compositions and concentrations. This chart also shows the final or true lactose solubility as determined by Hudson[139, 145] and the supersolubility curve as designed by Leighton and Peter.[150] The area between the final solubility curve and the supersolubility curve is the meta-stable area. In the lower temperature region of this area, immediately above the supersolubility curve, is the area where forced crystallization is most effective. This region is indicated by the "forced-crystallization curve." This curve is located 10° C. (18° F.) above the supersolubility curve. The milk should be cooled rapidly to the temperature of the forced crystallization curve, then seeded at once and further cooling should be arrested for preferably 45 to 60 minutes, so that the temperature will not drop below the supersolubility curve but will remain slightly above it. During this holding period the vigorous agitation of the milk is continued.

This chart, Fig. 48 and concrete examples explaining its use are given in Chapter IX on "Cooling Sweetened Condensed Milk." Extensive experience and observation in the manufacture of sweetened condensed milk on a commercial basis have demonstrated that the optimum temperature of the forced crystallization period for sweetened condensed milk of any given lactose-in-water concentration is somewhat flexible. Within the usual range of lactose concentration in sweetened condensed milk satisfactory results are obtained by seeding the milk when cooled to approximately 92° F. and retarding the cooling sufficiently to prevent the temperature from dropping below 75° F. during the forced crystallization period. Within this range of temperature (92°F.—75°F.) the forced crystallization period should occupy not less than one hour.

The above procedure applies particularly to the batch system of cooling. It has proven very effective when cooling in revolving cans and in the coil vat. In the case of the continuous system of cooling, where the condensed milk is pumped through coils submerged in or surrounded by the cooling water, no time need be allowed for the forced crystallization period and the cooling need not be retarded. On the basis of commercial experience it appears that the coating of old milk adhering to the inside of the coil walls and the nature of agitation provided by the flow of condensed milk through the coils, render the seeding so effective that mass crystallization is almost instantaneous, rendering retardation of the cooling process unnecessary.

Continued Agitation Beneficial.—It was pointed out in Chapter XXIII under "Solubility of Milk Sugar" that, as the temperature drops, lactose solubility diminishes, the solution becomes supersaturated and, other conditions being favorable, mass crystallization is encouraged. Because of its low solubility the alpha-lactose present in excess of saturation crystallizes out. This disturbs the 1.58 to 1 ratio of beta-to alpha-lactose, hence more beta-lactose changes back to alpha-lactose. This change continues with the lowering of the temperature and thus progressively provides more lactose for crystallization.

It was also explained that, as the temperature drops, the condensed milk becomes more viscous and that this increased viscosity retards the change from beta- to alpha-lactose and the crystallization of lactose (alpha-lactose).

The optimum temperature for the forced crystallization period and for mass crystallization, therefore, lies within that temperature range that provides minimum lactose solubility consistent with minimum viscosity. That temperature range is indicated by the "Forced Crystallization Curve," shown in Fig. 48. The forced crystallization period will reduce the state of supersaturation to the state of saturation for that temperature. But, as the cooling is continued to the final temperature, lactose solubility decreases still further, the lactose solution again becomes supersaturated and crystal growth is invited. On account of the great viscosity of the cooled milk the formation of new crystals is retarded, and unless it is facilitated by continued agitation, the lactose present in solution in excess of saturation will not form new crystal centers, or only sparingly so, but will furnish food for the subsequent gradual and progressive growth of the crystals already present. The inevitable result then is larger crystal units and an increasingly sandy texture.

Sweetened condensed milk is invariably smooth and never sandy immediately after cooling. In this viscous cooled milk the transfer of lactose and the resulting crystal growth are slow. However, unless the formation of new crystals is encouraged, crystal growth will occur and the permanent smoothness of the product is jeopardized. In order to avoid this, and to render the condensed milk permanently smooth, it is essential to induce the formation of enough new crystal centers to reduce the state of supersaturation to a permanent state of saturation at the final (low) temperature as rapidly as possible. This is best accomplished by continuing the agitation of the condensed milk for several hours after the final cooling temperature has been reached. This precaution is advisable regardless of type of cooling system used.

Relation of Sucrose to Sandiness.—The sugar crystals contained in normal sweetened condensed milk are lactose crystals. It has been shown by Hunziker and Nissen[147] that concentrated solutions of sucrose, such as sweetened condensed milk represents, have a tendency to depress the lactose solubility to a limited extent, see Chapter XXIII. This slight decrease in lactose solubility does not materially influence the control of lactose crystallization and is not a factor in the prevention of sandiness.

When the amount of sucrose in sweetened condensed milk is increased to a point where the sucrose-in-water concentration exceeds 64.5 per cent, the condensed milk approaches the status of a saturated sucrose solution. When such condensed milk is stored at low temperature (40° F. or below) there is a tendency for the sucrose that is present in excess of saturation to crystallize and to make the condensed milk sandy or gritty. A sucrose-in-water concentration of 65 to 66 per cent will produce sandiness at temperatures between 50 and 60° F. The crystals so formed are typical sucrose crystals, they are invariably of relatively large size. Sandiness caused by excessive sucrose concentration will occur regardless of proper methods of cooling and efficient control of lactose crystallization.

Incomplete solution of the sucrose at the time it enters the vacuum pan may, under certain conditions, be a contributing cause of sandiness. This tendency is confined largely to instances where so high a concentration of the milk is aimed at that the milk sugar is present in saturation at vacuum pan temperature and where incompletely dissolved sucrose reaches the pan toward the end of the condensing process. In such cases the undissolved sucrose crystals may serve as nuclei for lactose crystallization, causing larger crystal aggregates to develop before the milk reaches the forced crystallization period. It is advisable, for this as well as for other reasons, to insure complete solution of the sucrose before it enters the pan.

Relation of Milk Solids to Sandiness.—Neither the fat nor the colloids of milk appear to have any noticeable effect on lactose solubility. They, therefore, do not enter into the problem of lactose crystallization control and are not believed to bear any relation to sandy sweetened condensed milk, as shown by the lactose solubility determinations of Hunziker and Nissen[147] and by the study of the causes of sandiness in ice cream by Dahle,[173] Lucas and Spitzer,[174] and Williams and Peter.[138] For details see Chapter XXIII on "Composition and Properties of Condensed Milk."

Under certain conditions the salts of milk may become a factor in the development of sandiness in the sweetened condensed milk. When using very high forewarming temperatures some of the milk salts may precipitate and these insoluble ash particles may serve as nuclei, which, similar to lactose crystal centers, might induce slow crystallization and gradual growth of crystal aggregates in the upper temperature regions of the meta-stable area. This would automatically lead to the presence in the condensed milk of crystals of sufficient size to give the product a gritty character. At ordinary forewarming temperatures the precipitation of milk salts is negligible and the danger of sandiness from this source is remote.

Relation of Concentration of Milk to Sandiness.—As the concentration of the milk increases the per cent lactose-in-water increases. On the basis of an equal percentage of sucrose in the finished product, a highly concentrated milk is usually one in which the lactose content is high and the water content low. This combination of conditions augments the difficulties of accomplishing smoothness of texture and freedom from sandiness. The more lactose the condensed milk contains in proportion to its water content, the higher the temperature of saturation and the greater the danger of lactose crystal formation while the milk is still in the pan or before it has been cooled to the temperature of forced crystallization. It is for this reason that sweetened condensed skimmilk is more inclined to show sandiness than the unskimmed product, the ratio of milk solids not fat to water, and therefore the ratio of lactose to water, usually being higher in the condensed skimmilk than in the condensed whole milk. The greater sluggishness (viscosity) of the highly concentrated milk retards its discharge from the pan and its rapidity of cooling, which, in the absence of vigorous agitation, further encourages the development of large crystal aggregates and subsequent sandiness. This tendency may, however, be completely avoided by the intelligent application of the forced crystallization chart, Fig. 48 and the practice of continued agitation after cooling to the final temperature, as directed in previous paragraphs and in Chapter IX on "Cooling Sweetened Condensed Milk."

Effect of Re-warming Too Cold Condensed Milk on Smoothness.—Warming condensed milk that has become too cold, either because of accidentally cooling to too low a temperature or because of holding it in a very cold room, so that it is too thick to run through the filling machine, may cause the development of sandiness, when such milk is vigorously agitated during the warming. Setting the cans back into the cooling tank, inserting the stationary paddles, and revolving the cans in warm water will almost invariably make very rough milk.

The reason here probably lies in the fact that this agitation, while warming, tends to cause the smaller crystals to redissolve, increasing the supersaturation and facilitating diffusion. This greatly reduces the number of crystal centers and causes the crystals that are left to grow in size and form large enough aggregates to give the milk a very sandy character.

This explanation is also supported by the "Heat Shocking Theory" discussed by Dahle[173] in the case of sandy ice cream and who defines heat shocking as follows: "By heat shocking is meant the practice of permitting the frozen ice cream to become slightly softened by exposure to warmer air, and immediately frozen again." This, according to Zoller and Williams,[175] causes greater and more rapid growth of lactose crystals in ice cream. This effect is attributed by Evans[176] to "an increase in diffusibility, resulting consequently in a more rapid formation of lactose crystals," but which in fact probably results in a decrease in number of crystals due to solution of some of the smaller ones, and an accelerated surface growth of the remaining crystals. It has been found that sandiness resulting from rewarming too cold milk may be avoided by tempering the milk without agitation.

SETTLED SWEETENED CONDENSED MILK

General Description.—This defect refers to sweetened condensed milk in which a portion of the sugar crystals have dropped to the bottom of the tin or barrel, forming a layer of sugar deposit varying in thickness from a thin film to a layer an inch or more thick. The physical character of this sediment varies in different cases. It may be soft and, upon stirring, may readily emulsify with the contents, or it may be coarse, hard and dry, in which case it adheres with great tenacity and refuses to emulsify with the milk. Settled milk is a common condensed milk defect and it is objected to by the trade.

Both microscopic and chemical analyses of the sediment in sweetened condensed milk have shown it to consist essentially of lactose crystals. The fundamental cause of settled milk lies in the fact that lactose is heavier than the condensed milk. The specific gravity of lactose is 1.54 and the specific gravity of condensed milk falls within a range of approximately 1.285 to 1.33, according to the concentration and percentage of fat and sucrose.

As has been explained under "Sandy Sweetened Condensed Milk," lactose crystals are always present in the cooled product and since their specific gravity exceeds that of the remainder of the concentrated product, their tendency is to settle to the bottom of the container when at rest. This tendency to settle is greatly influenced by the size of the crystals, the viscosity and concentration of the milk.

Effect of Crystal Size on Sediment.—The size of the lactose crystal is the controlling factor that determines whether the sugar will settle or not. Other conditions being equal, the smaller the lactose crystals the less the danger of settled milk. Milk in which the lactose crystals do not exceed .010 millimeter in length usually remains entirely free from sugar sediment. In these minute crystals the surface area is so large in proportion to their cubic content that they are unable to overcome the resistance of the viscous fluid surrounding them to respond to the force of gravity. They cannot settle to the bottom, but remain in permanent suspension.

Because of the above fact the problem of preventing sugar sediment in sweetened condensed milk is clearly a problem of crystal size control. Its solution lies in so adjusting the method of cooling as to provide mass crystallization that rapidly reduces the state of supersaturation to a state of saturation, thereby preventing the formation of large crystal aggregates. It is a problem of preventing sandiness as discussed in previous paragraphs. Sweetened condensed milk in which the lactose crystals are so small that its texture is permanently smooth, velvety and free from sandiness will not usually settle.

Effect of Density on Sugar Sediment.—The more concentrated and therefore the heavier the condensed milk, the smaller the difference in specific gravity between lactose crystals and surrounding milk, and the less the tendency for the crystals to settle. The increased viscosity of the more highly concentrated milk is of further assistance in keeping the crystals in suspension.

The relative proportion of milk fat and sucrose also influences the settling tendency largely because of their effect on the specific gravity of the milk. The lower specific gravity of condensed whole milk encourages settling, hence sugar sediment forms somewhat more readily in the former than in condensed skimmilk. An increase in sucrose content diminishes the tendency to settle because of the higher specific gravity of high-sucrose milk.

Effect of Viscosity on Sugar Sediment.—Other conditions being the same, the greater the viscosity of the milk, the less the tendency for the sugar crystals to settle to the bottom. The viscosity increases the resistance which the crystals encounter in their response to the force of gravity. The factors, other than the concentration of the milk, that control the viscosity of sweetened condensed milk are discussed in detail in succeeding paragraphs under the caption "Thickened and Cheesy Sweetened Condensed Milk."

Turning the Cans to Prevent Sugar Sediment.—Turning the cases daily or at longer intervals keeps the sugar in motion and minimizes the accumulation of sugar sediment somewhat. At times, when the market is brisk and the milk moves fast, this may be of considerable service to avoid complaints from the trade. Turning the milk, is, however, of temporary benefit only, it does not prevent settling after the milk leaves the factory.

PROGRESSIVE THICKENING IN SWEETENED CONDENSED MILK

General Description.—A very common defect to which sweetened condensed milk is subject is its progressive thickening with age, particularly when stored at high temperatures (room temperature or above). The manufacturer of condensed milk knows from experience that the tendency for the milk to thicken in storage is especially pronounced in the case of milk manufactured in late spring and early summer, but this defect may occur with any milk stored for a considerable period of time above room temperature.

While the exact reactions involved in the progressive thickening of sweetened condensed milk have not as yet been established conclusively, this defect has been studied by numerous investigators and sufficient data are available to indicate that this thickening may be due either to bacterial action or to spontaneous physico-chemical changes, or both.

Bacterial Thickening.—When the progressive thickening is due to bacterial action it is usually, though not always, accompanied by increased acidity, a disagreeable, stale and often cheesy odor and taste, and a relatively high bacterial count. When this thickened milk is diluted with water and heated the curd separates.

Andrews[177] found large numbers (from 100,000 to 1,000,000 per gram) of S. pyogenes and Staph. aureus and albus in sweetened condensed skimmilk that had thickened. Cooksey[178] reports thickened sweetened condensed milk with high acidity and from which he isolated staphylococci, B. subtilis, B. mesentericus, and yeast. Greig-Smith[179] also found large numbers of cocci in sweetened condensed milk that had coagulated (thickened) and Dugardin's work[180] shows that thickened milk had a high acidity.

The above observations were largely confined to making bacteriological counts from commercial samples of sweetened condensed milk, but no effort was made to reproduce the thickening by inoculating sound tins with pure cultures of the predominating species found in the defective milks. In most instances their results show the presence of large numbers of bacteria, with cocci forms predominating.

The work of Rice and Downs[162] and later of Downs[181] appears to offer the only available published evidence that certain species of bacteria are capable of causing rapid thickening of sweetened condensed milk. Rice and Downs found the bacterial thickening to be due to the presence of a coccus which they isolated from practically all samples of sweetened condensed milk purchased on the market. They found this organism capable of inverting and destroying sucrose, producing acid. It grows in a wide range of sucrose concentrations but is inhibited in concentrations that approach the sucrose saturation point. It is most active at temperatures above ordinary room temperature.

While their work stopped short of the differentiation of the exact species of bacteria, they determined that these cocci had a sufficiently low thermal death point (64° C.) to be readily destroyed by the heat of forewarming. They, therefore, concluded that these cocci are not carried into the condensed milk from the fresh milk, but that the condensed milk becomes contaminated with them in the factory between the pan and the sealed tins. Their conclusion concerning source of contamination is further supported by the fact that they were able to secure in the factory inoculating material from different places and equipment, such as packing from the cooling vat, wall and floor scrapings, slime from a cheese curing room, etc. This material was inoculated into normal condensed milk in which the concentration had been reduced with water to 70, 65 and 60 per cent total solids. After incubation of two weeks, all samples had become nearly solid, the acidity had increased and bacteriological analyses showed almost pure cultures of these cocci. No check samples were made, however, to study the effect of water dilution without inoculation.

Effect of Sucrose Concentration on Bacterial Thickening.—A detailed study by the same authors of the resistance of these cocci to high concentrations of sucrose and of milk solids showed that, while the concentration of milk solids had no appreciable influence on bacterial thickening, the development of the cocci could be inhibited and bacterial thickening prevented by increasing the sucrose concentration. The exact sucrose concentration required to accomplish this depended on the number and vigor of cocci present. When the sucrose-in-water concentration was above 61 per cent, cocci growth was inhibited and bacterial thickening prevented in the case of moderate inoculation with the ordinarily, more or less dormant forms of these bacteria. But when the condensed milk was seeded liberally with specially invigorated cultures of cocci, a sucrose-in-water concentration as high as 64.5 per cent was required to check bacterial thickening dependably.

As explained under "Sandy Sweetened Condensed Milk," a sucrose-in-water concentration of 64.5 per cent approaches the saturation point of sucrose, and when condensed milk with so high a sucrose concentration is stored at low temperatures (40° F. or below), sucrose crystallization and sandiness may result. However, bacterial thickening may be very greatly retarded at somewhat lower sucrose concentrations when the milk is stored at reasonably low temperatures. A sucrose-in-water concentration of 62.5 per cent is usually adequate to avoid bacterial thickening when the condensed milk is manufactured and handled under properly sanitary factory conditions that protect it against abnormal contamination, and when stored below room temperature.

Rice and Downs[162] observed further that bacterial thickening was invariably accompanied by a marked increase in the titratable acidity calculated as lactic acid, and a change in the odor and flavor of the milk. Milk that had thickened usually showed over .35 per cent acid, the acid in the majority of the thickened samples was between .50 and .75 per cent and in extreme cases it was over one per cent. The odor they termed fruity, not unpleasant, and the flavor "disagreeable." Their description suggests that the milk which they inoculated in their experiments and that consequently thickened developed an odor and flavor similar to that which is characteristic of a good deal of the commercial sweetened condensed milk that has thickened. On the strength of the high acidity found in the thickened milk they suggest that the thickening may be the direct result of the coagulation of the casein in the presence of high acidity. The importance of acid coagulation as the primary cause of bacterial thickening, however, fails to be substantiated by the results of later study by Downs.[181]

In subsequent work on bacterial thickening of sweetened condensed milk Downs studied a number of organisms causing thickening and found them to belong to one general type of micrococcus of which he described two distinct varieties. Many organisms of common occurrence closely resembled these and could be distinguished from the thickeners only by their effect on the condensed milk. Downs believes, therefore, that the thickening action is due to the production of a rennin-like enzyme by the responsible organism, rather than to acid coagulation of the casein. Not all the thickening organisms inverted sucrose, nor produced high acid. Some of the acid producers failed to thicken the milk, and in litmus milk the thickening bacteria caused sweet curdling and produced a rennet curd.

The above findings and conclusions do not preclude the possibility, however, of a thickening of the sucrose solution itself as the result of bacterial action. Unpublished experimental results by Cordes[182] indicate that certain species of bacteria, capable of thriving in concentrated sucrose solutions are capable of greatly increasing the viscosity of the sucrose solution. Cordes found a coccus of slightly elongated contour that made sucrose solutions extremely viscous and ropy. He is inclined to attribute this condition to the presence of these organisms in chains and in such numbers as to bring this condition about through the mechanical adhesion of these germs to one another in large numbers, in a sense similar to the effect produced by occasional cultures of S. lactis and L. bulgaricus which may cause milk and cream to become viscous and ropy.

For the prevention or control of bacterial thickening in commercial manufacture, the available experimental results suggest the following:

1. Forewarm at temperatures sufficiently high to insure destruction of the type of bacteria causing thickening. The thermal death point of these organisms in beef broth has been found to be 64° C. (147.2° F.) for ten minutes. The usual forewarming temperature of 170° F. and above should therefore be ample to accomplish this, provided that the milk is heated to the maximum forewarming temperature before sucrose or condensed milk are added. As shown by Rice,[36] the presence of sucrose increases the resistance of enzymes to heat.
2. Protect the condensed milk against contamination from unclean equipment and impure air between vacuum pan and sealed tin by maintaining a high standard of sanitation of all equipment and operations and by not exposing the milk excessively to the factory air.
3. Store the condensed milk at temperatures below ordinary room temperature.

Thickening Due to Physico-Chemical Causes.—Another type of thickening, that appears to differ in its reaction, results and causes from the bacterial thickening described in the foregoing paragraphs, relates to a progressive increase in the viscosity of the sweetened condensed milk which is not accompanied by acid production nor by the development of a distinct, disagreeable flavor. When the milk is diluted with water there is no separation of curdy flakes and in the earlier stages the thickened condensed milk can be stirred back into a homogeneous liquid that resembles the original fluid condition of the milk. In advanced stages, however, it forms a jelly-like character which is permanent. This type of thickening is believed to be due to changes in the colloidal structure of the milk proteins and to be controlled by factors other than bacteria.

The colloidal thickening of sweetened condensed milk has been studied experimentally by Rogers, Deysher and Evans,[64] Leighton and Deysher,[34] and Stebnitz and Sommer.[35] The exact reactions involved in age thickening are not as yet fully understood, but the effect of numerous factors on age thickening has been fairly definitely established. The knowledge thus made available has been of much value to the manufacturer in his efforts to guard against this defect. The factors influencing age thickening are briefly discussed in the following paragraphs.

Effect of Temperature of Storage on Age Thickening.—The progressive thickening of sweetened condensed milk after manufacture is very largely controlled by the temperature of storage. On this fact all available experimental results and the experience of the manufacturer agree. At temperatures below 45° F. the viscosity of the condensed milk remains practically constant indefinitely. As the temperature rises the tendency of thickening increases. At ordinary room temperature (68 to 70° F.), this increase in viscosity is still very gradual; but it is continuous. Above 70° F. the viscosity increases considerably more rapidly, and between 90 and 100° F. the milk becomes custard-like in about thirty days. The most effective means to prevent age thickening, therefore, lies in storing below room temperature and preferably at or below about 45° F. After the milk leaves the factory or the factory controlled storage, however, its exposure to a wide range of temperatures becomes unavoidable, particularly in the case of canned goods. If age thickening is to be dependably guarded against therefore, there is need of attention also to factors other than storage temperature that influence this defect. One of the most important of these is the temperature of forewarming.

Effect of Forewarming Temperature on Age Thickening.—Forewarming temperatures up to approximately 167° F. have but little effect on age thickening; in fact these forewarming temperatures slightly diminish the thickening tendency as compared with unforewarmed milk. Above 167° F. and up to near the boiling point (210° F.), the forewarming temperature unstabilizes the milk and increases the age thickening tendency. The effect is particularly pronounced within the forewarming range of 185 to 203° F. Forewarming temperatures above the boiling point (especially between 231 and 248° F.) increase stability and diminish the tendency of age thickening.

Rogers and co-workers found the viscosity of condensed milk, forewarmed at 145.4° F. for 20 to 30 minutes very low, and the tendency for the viscosity to increase in storage much reduced. The low viscosity, however, caused a slight separation of the fat. For commercial manufacture so low a forewarming temperature is not recommended, because of the tendency of the finished product to develop rancidity, as explained under "Rancid Flavor in Sweetened Condensed Milk" later in this chapter.

Because of the above facts, the most effective means of stabilizing the milk and of minimizing its tendency to thicken with age, as far as the method of manufacture is concerned, lies in the proper control of the temperature of forewarming. Unless the factory facilities permit of raising the forewarming temperature above the boiling point (230 to 245° F.), a practice which requires the use of closed pressure heaters, see Chapter IV on "Forewarming," it is advisable to limit the forewarming temperature to 167-170° F. An exposure to this heat for 10 to 15 minutes is sufficient to destroy enzymes and bacteria damaging to keeping quality, especially if the milk is heated before sucrose or remnants of sweetened condensed milk have been added. This temperature limit is sufficiently low to prevent unstabilizing of the proteins to such an extent as to cause objectionable age thickening. See also succeeding paragraphs.

Relation of Casein and Albumin to Age Thickening.—The constituents of milk that are directly responsible for age thickening are the milk proteins, the casein and albumin; the casein, probably due to the unstabilizing effect of heat on the casein-calcium balance, casein hydration and swelling; the albumin as the result of heat coagulation.

The effect of the milk proteins on age thickening was studied by Rogers and co-workers.[64] Normal skimmilk, portions of the same product from which the casein had been removed, and portions from the same milk from which the albumin had been removed, were used. These several portions were forewarmed in each case at 63° C. (145.4° F.) and 96° C. (204.8° F.) respectively, and the condensed milk was stored at 30° C. (86° F.). The results are shown in Tables 36 and 37.

Table 36.—Relation of Albumin and Casein to Progressive Thickening of Sweetened Condensed Skimmilk. Forewarming Temperature 63°C. (145.4°F.)

Age	Viscosity expressed in degrees rotation of Clark viscosimeter telescope scale		
	Normal condensed skimmilk.	Casein removed.	Albumin removed.
days	Rotation, degrees	Rotation, degrees	Rotation, degrees
2	3.0	1	1
9	2.5	1	1
30	4.5	1	8
74	37.0	1	130

Table 37.—Relation of Albumin and Casein to Progressive Thickening of Sweetened Condensed Skimmilk. Forewarming Temperature 96°C. (204.8°F.)

Age	Viscosity expressed in degrees rotation of Clark viscosimeter telescope scale		
	Normal condensed skimmilk.	Casein removed.	Casein and albumin removed.
days	Rotation, degrees	Rotation, degrees	Rotation, degrees
2	18	6	1
9	130	8	1
32	Beyond range	15	1

The figures in the above tables show that the casein is the constituent principally involved in age thickening. At the lower forewarming temperature (145.4° F., 30 minutes) the thickening effect, though gradual only, was due entirely to the casein. At the higher forewarming temperature (204.8° F.) the thickening effect was very rapid. There was some thickening also with the casein removed, showing that the albumin becomes a factor when the forewarming temperature is much above the coagulation point. Absence of both casein and albumin eliminated all increase in viscosity at either temperature.

Effect of Concentration of Sucrose on Age Thickening.—Rogers and co-workers[64] report the results of an experiment in which different lots of condensed milk of 54, 58 and 62 per cent sucrose, respectively, were used. The sucrose concentration increased the initial viscosity slightly. The viscosities of the milk containing a 58 per cent and 62 per cent sucrose solution, respectively, increased slightly in 32 days but maintained their initial relation. The milk containing the 54 per cent sucrose solution increased its viscosity slowly at first but with increasing rapidity until at 32 days it was a firm jelly. The authors suggest that the odor and flavor of this milk, as well as the nature of the curd, indicated that the low sucrose concentration permitted the growth of bacteria which undoubtedly accounted for the greatly increased viscosity. They conclude that sucrose increases the initial viscosity slightly, but affects the increase in viscosity only as it inhibits the growth of bacteria.

The above deductions are in accord with the findings of Rice and Downs[162] who showed that in milk with a low sucrose ratio (below 61 per cent sucrose), bacterial thickening may set in, especially at the high storage temperature (86° F.) used in the above experiment. The forewarming temperature in the above experiments, however, was only 48° C. (118.4° F.). If a forewarming temperature high enough to encourage colloidal thickening had been used, it is possible that the sucrose concentration might have shown a more pronounced influence on viscosity. Leighton and Deysher,[34] as the result of later work, believe that the influence of sucrose, aside from its dilution effect, lies in a chemical effect caused by its action upon the metallic salts of the milk. Their results indicate that at forewarming temperatures from 65 to 75° C. (149 to 167° F.) the milk containing sucrose suffers less increase in viscosity than unforewarmed milk, while forewarming the same milk to between 85 and 95° C. (185 to 203° F.) causes a rapid increase in viscosity.

Experience in commercial manufacture shows, as pointed out by Hunziker,[94] that age thickening of sweetened condensed milk is especially pronounced in late spring and early summer, while at any other time of the year it is more easily controlled. Hunziker further found that an increase in the amount of cane sugar added, greatly minimized the thickening tendency, even in the milk made in early summer. These experiences and observations suggest three explanations for the viscosity-stabilizing effect of the higher sucrose concentrations.

1. The thickening tendency may be due to bacterial action, in which case an increase in amount of sucrose has an inhibitive effect, as shown by Rice and Downs, and thus retards the thickening action.

2. The increased thickening tendency in early summer may be due to a relatively high albumin and casein content (especially albumin) of milk from recently freshened cows, and the higher sucrose concentration may physically hinder hydration and swelling.

3. The higher sucrose concentration may intensify the modifying influence of sucrose on the effect of forewarming, as previously pointed out by Leighton and Deysher, who suggest the possibility that sucrose may affect the salt equilibrium established at a given temperature of forewarming, by reacting with the metals or by dissolving some otherwise insoluble calcium or magnesium salts.

The very marked age stabilizing effect of sucrose concentrations in excess of concentrations already sufficient to inhibit the growth of thickening bacteria, strongly suggests that this influence of sucrose is not confined exclusively to its preservative action, but involves, in all probability, chemical and physical reactions as well.

Influence of Concentration of Milk on Age Thickening.—It has long been known in commercial manufacture that the tendency of thickening increases with an increase in the concentration of the milk solids. This has led to the practice in some condenseries to condense to a lower concentration at times of the year when the milk shows abnormal tendency to thicken, as experience has shown to be the case in early summer. Rice and Downs' experiments indicated that bacterial thickening is not influenced noticeably by the concentration of the milk solids but is practically controlled by the sugar ratio. Rogers, Deysher and Evans on the other hand, show that the concentration of milk solids plays a very prominent part in the thickening due to physical changes, when milk is forewarmed at the high temperatures used in general condensery practice. Their experiments were conducted with sweetened condensed skimmilk concentrated to contain 20, 24, 26, and 28 per cent milk solids.

One set of these milks was forewarmed at 60° C. (140° F.)

and a second set at 80° C. (176° F.). The sucrose-in-water concentration of all milks was 60 per cent, and all samples were stored at 30° C. (86° F.). The results are shown in Tables 38 and 39.

Table 38.—Relation of Concentration of Milk Solids to Progressive Thickening of Sweetened Condensed Milk. Forewarming Temperature 60°C. (140°F.)

Age	Milk solids not fat		
days	20 per cent Rotation, degrees	24 per cent Rotation, degrees	28 per cent Rotation, degrees
1	0.5	1.25	2.25
13	1.0	1.00	2.50
25	1.0	1.00	4.00
35	1.0	1.00	8.00

Table 39.—Relation of Concentration of Milk Solids to Progressive Thickening of Sweetened Condensed Milk. Forewarming Temperature 80°C. (176°F.)

Age	Milk solids not fat		
days	24 per cent Rotation, degrees	26 per cent Rotation, degrees	28 per cent Rotation, degrees
1	2.0	3.0	5.25
12	3.0	10.0	25.00
24	5.0	19.0	130.00
34	7.5	25.0	Beyond range

The above tables again show the effect of the forewarming temperature. The age thickening effect was much more pronounced at the higher forewarming temperature. As the concentration of milk solids increased age thickening also increased. This increase in progressive thickening due to increased concentration was very pronounced at the higher forewarming temperature. But it was not in direct proportion to the concentration, it increased much more rapidly at a concentration of 26 to 28 than at the lower concentrations.

Effect of Mineral Salts on Age Thickening of Sweetened Condensed Milk.—It was shown in Chapter XXIII that the heat coagulation point of milk depends to a considerable extent on the interrelation of the ash constituents, on the combination in which they are present with other milk constituents, particularly the casein, and that this combination is more or less disturbed by heat. These facts suggest the possibility of a relation between ash constituents and age thickening of sweetened condensed milk.

Rogers, Deysher and Evans[64] found that the addition of citrate to the extent of 2.8 grams of calcium citrate per 3,500 grams of milk had no appreciable effect on the viscosity of milk forewarmed at 145° F. and stored at 68° F. for 58 days. The addition of phosphates in amounts to raise the total phosphates by 7 to 11 per cent caused a decided increase in the thickening tendency even in 23 days, and much more so in 44 days.

Stebnitz and Sommer[35] studied the effect of calcium acetate, sodium citrate and di-sodium phosphate on age thickening and concluded that if the milk was stable, the addition of salts tends to unstabilize it. They further report that there was no correlation between the alcohol test of the fresh milk and age thickening, but that alcohol-positive milk is stabilized by the addition of sodium citrate while calcium acetate has no effect. In the case of alcohol-negative milk, both the calcium and the citrate were effective in stabilizing the finished product.

Leighton and Deysher demonstrated that the effect of forewarming temperature on the stability of sweetened condensed milk is practically the reverse of the effect of the same forewarming temperature on evaporated milk, and they attribute this phenomenon, aside from the diluting effect of the sucrose, to the latter's chemical effect as related to the salt equilibrium.

The above observations suggest that the salt balance may play an important role in the control of age thickening. The data are too limited, however, to justify the addition of salts as a means of preventing age thickening in commercial operation.

Effect of Acidity on Age Thickening.—Other factors being equal, an increase in acidity almost invariably diminishes the heat stability of milk. It appears reasonable to expect, therefore, that the acidity of milk has a definite influence on age thickening of sweetened condensed milk, and that the thickening tendency increases with an increase in the acidity of the milk.

The above assumptions are borne out by the work of Stebnitz and Sommer[35] who found that when the acidity of the milk was lowered from pH 6.721 to 6.858 by the addition of sodium hydroxide, the condensed milk was more stable to age thickening. Increasing the acidity from pH 6.721 to 6.589 and 6.499 by addition of lactic acid caused a marked decrease of stability as the pH decreased.

Rogers, Deysher and Evans[64] in earlier work, however, found no appreciable effect of the acidity on age thickening. Neither partial neutralization, nor the addition of lactic acid changed the thickening tendency of the concentrated product noticeably. They therefore concluded that "acidity within reasonable limits, has no significant influence on the increase of viscosity of sweetened condensed milk."

It appears probable that the negative effect of acidity in the case of the results of Rogers and co-workers was due to the low forewarming temperature used (145° F.), and that with a higher temperature of forewarming the milks with the higher acidities would have shown the expected decrease in stability and in resistance to age thickening.

Effect of Vacuum Pan Temperatures on Age Thickening.—The pan operating temperature, the temperature at which the batch is finished and the rapidity of drawing it from the pan are additional important factors that influence the progressive thickening of the concentrated product.

Finishing the batch at a relatively high temperature (150° F. or above) yields a product with higher initial viscosity and greater age thickening tendency than finishing at relatively low temperatures (120 to 130° F.). The thickening tendency due to high finishing temperature is augmented by delay in drawing the condensed milk from the pan. This influence is further intensified in the presence of leaky valves at coils and jacket, thus magnifying the damaging superheating effect.

In order to eliminate, as far as possible, vacuum pan operation as a factor in age thickening, the pan temperature toward the end of evaporation should be held as low as consistent with maximum rapidity of condensing, preferably at 130° F. or below, the finished batch should be drawn from the pan promptly, and leaky steam valves should be avoided. These precautions are particularly important at a time of the year (late spring and early summer) when the condensed milk is least stable and is most susceptible to age thickening.

Influence of Season of Year on Age Thickening.—It has long been known by the manufacturer, as pointed out by Hunziker,[94] that the season of the year is an important factor in the stability of sweetened condensed milk toward progressive thickening. Commercial experience has shown that the tendency of the condensed milk to thicken in storage is greatest in the case of milk manufactured in late spring and early summer and least in late fall and throughout the winter months. Efforts to minimize the abnormal thickening tendency of summer milk have led to the practice of increasing the sucrose concentration and lowering the solids not fat in early summer.

Recent experimental study by Stebnitz and Sommer[35] confirms the above commercial experience. These investigators report that "Milk condensed during November remained liquid for over a month when stored at 98.6° F., while that condensed during the latter part of May became solid in a few days."

LUMPY SWEETENED CONDENSED MILK

General Description.—Lumps of varying denominations are not infrequently found in sweetened condensed milk. They may be soft and permeate the contents of the can throughout, or may appear especially in the form of a "smear" along the seams of the can; or again, they may float on the surface, in which case they are usually hard and cheesy, and either white or yellow in color.

The chief causes of lumpy condensed milk are poor quality of fresh milk, unclean pipes in factory, milk from fresh cows too soon after calving, acid flux in tin cans and unclean and contaminated cans.

Poor Quality of Fresh Milk and Unclean Factory Conditions.—Upon opening the can of condensed milk, even shortly after it is filled, the lid is covered with large and small lumps and specks sticking to the tin, presenting a very uninviting appearance. This condition can usually be traced back to a poor quality of fresh milk, containing too much acid, and recurrence of the defect may be prevented by more rigid inspection of the incoming milk on the receiving platform.

In some cases, however, the cause lies in the factory itself, where it is usually found to be due to a foul condition of milk pipes or other equipment. In such cases a thorough inspection of milk pipes, pumps, filling machines, etc., generally shows accumulations of remnants of milk which get into the milk of the succeeding batch. Where this condition exists, it is usually noticeable that the first batch of the day contains more specks and lumps than the succeeding ones. These lumps do not, as a rule, grow larger in size nor increase in number with the age of the condensed milk, but they are unsightly and certainly cannot add to the wholesomeness of the milk. A more rigid inspection of all the fresh milk as it arrives at the factory and thorough scouring of all milk tanks and milk pumps, pipes and conveyors, milk coolers and filling machines usually prevents the recurrence of this defect.

Milk from Fresh Cows.—During early spring there is a strong tendency of the jacket and coils in the vacuum pan to become coated with a thick layer of gelatinous and lumpy milk. This is probably due to the fact that milk during these months comes largely from freshened cows and may contain some colostrum milk or milk which still contains an abnormally high content of albumin and lactoglobulin. These proteins are sensitive to heat and readily coagulate when in contact in high concentration with the hot heating surfaces of coils and jacket. This thickened material usually does not leave the pan until most of the condensed milk has been drawn off. It, therefore, appears in the last portion drawn. If this lumpy milk is mixed with the rest of the condensed milk, the lumps will appear in the tins of the entire batch. Where this difficulty occurs it is advisable to set aside in separate containers that portion of the batch which contains this lumpy material. This lumpy milk may be redissolved in hot water and should be recondensed in a succeeding batch to avoid unnecessary loss. More rigid inspection of the fluid milk will assist in minimizing the difficulty. Carrying low steam pressure in jacket and coils during pan operation and especially toward the end of the process, is the most effective means to guard against the formation of a heavy coating of milk on the heating surface.

Table 40.—Comparative Composition of Gelatinous Coating on the Jacket and Coils and of Normal Condensed Milk of the Same Batch.

	Coating on Jacket and Coils Per Cent	Normal Condensed Milk Per Cent
Moisture	24.76	30.34
Lactose	13.12	13.16
Fat	9.50	7.44
Curd	8.14	7.30
Ash	1.42	1.80
Acid	.33	.40
Sucrose	41.36	40.02
	98.63	100.46

Excess of Acid in Condensed Milk and Acid Flux in Tin Cans.—The presence in the condensed milk of organic and mineral acids, in excess of the amount derived from normal fresh milk, is conducive of the formation of lumps.

Excessive amounts of acid in condensed milk may be due to the presence in large numbers of acid forming bacteria, capable of thriving in concentrated sucrose solution, sucrose-fermenting yeast, or to the use of acid flux in the making and sealing of the tin cans. Condensed milk that shows acid or gaseous fermentation usually contains lumps. The acid which it develops as the result of the fermentation, curdles the casein with which it comes in contact.

One of the most common channels through which condensed milk may become contaminated with acid mechanically, is the use of cans, in the manufacture and sealing of which acid flux was used. The acid flux generally used contains zinc chloride. The flux precedes the solder and some of it is bound to sweat through the seams into the interior of the cans. Lumps from this source usually have a pink or brownish-red color, especially in the case of considerable quantities of acid flux. Zinc chloride is a highly poisonous product and should not be used in the manufacture of tin cans, which are intended for receptacles of human food. In such cans there usually develop along the seams, lumps and smeary substances which have been found to consist of caseinate of zinc.

Most commercial soldering fluxes consist largely of zinc chloride and are highly acid, although they may be advertised as acid-free fluxes. In order to avoid the appearance in condensed milk of lumps from this source, cans should be used, in the manufacture and sealing of which a strictly acid-free flux is used. Dry, powdered rosin or rosin dissolved in alcohol or gasoline is harmless in this respect and constitutes a satisfactory flux.

Buttons in Sweetened Condensed Milk.—Buttons, as known to the condensed milk manufacturer, represent a type of lumps, different from those previously described. Buttons are lumps of curd of a firm and cheesy consistency. They usually float on top of the condensed milk in the can or barrel. They are sufficiently firm units so they can be readily removed and washed free from the condensed milk. They are of varying sizes, depending on the age of the condensed milk and the temperature at which it was stored. The older the milk and the higher the storage temperature, the larger the buttons. In extreme cases they are frequently of sufficient size to cover the entire surface of milk in the tin.

These buttons have a whitish-brown to yellowish or reddish-brown color. They appear in old sweetened condensed milk more frequently than in milk that has been in storage for a short time only. They are entirely absent in freshly made condensed milk. They themselves have, and they give the condensed milk, a cheesy, stale flavor and lend the entire product an unsightly appearance.

Causes and Prevention of Buttons.—Experience has demonstrated that buttons are most prone to appear in stored condensed milk, in the packing of which no attention was given to sanitary conditions of the factory and of the cans or barrels. The use of clean sterile cans and barrels and a high standard of sanitation in the handling of the product before packing greatly minimizes this defect.

Rogers, Dahlberg and Evans[103] investigated the causes and control of buttons experimentally. They found that the buttons are caused by the growth of the mold Aspergillus repens, and possibly by other molds; that the development of the mold colony is restricted by the exhaustion of the oxygen in the can or barrel, and that the button itself is probably due to enzyme action, continued after the death of the mold. These findings corroborate earlier experimental results by the author, who was unable to develop growing mold colonies in normal sweetened condensed milk from inoculations with full-grown buttons.

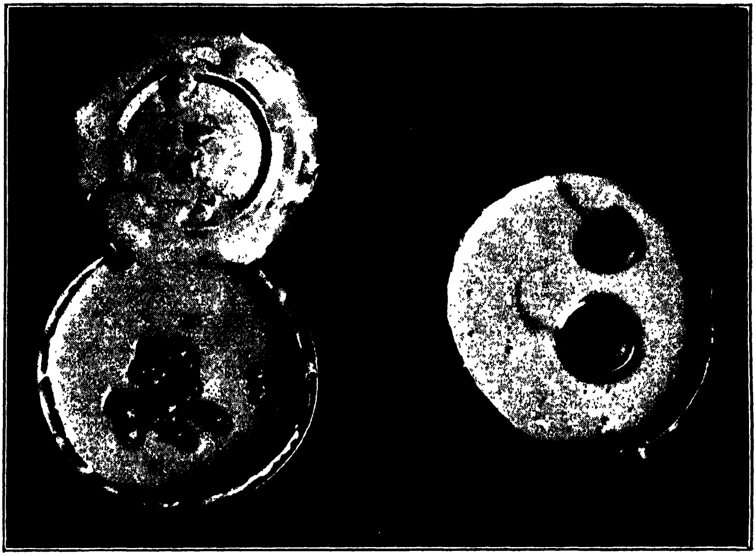


Fig. 106. Typical buttons of different sizes from which mold has disappeared
Courtesy of L. A. Rogers, U. S. Bureau of Dairy Industry

Rogers and co-workers demonstrated that the time required for the development of the various stages resulting in button formation varies with temperature, amount of air available and possibly other factors. The mold colony usually appeared in 5 to 10 days. Mold growth is supposed to cease in two to three weeks on account of the exhaustion of the air. In one month a reddish-brown discoloration became quite evident and at the end of two months the button had usually assumed definite form. The disintegration of the mold hyphae (filament) proved to be a slow process, extending over 5 to 6 months. The prevention or control of these buttons may be accomplished by: 1. exclusion of contamination, 2. low temperature, 3. exclusion of oxygen.

Exclusion of Contamination.—Contamination of the condensed milk with button-forming molds is most likely to occur during the cooling, holding and filling operations and as the result of contaminated cans and barrels.

In condenseries where the milk is cooled by the old method in open 10-gallon cans revolving in a cold water tank and stirred with wooden paddles, it is not difficult to understand the reason for buttons. In this system the condensed milk is exposed to the air for hours, the 10-gallon cans and the wooden paddles are seldom sterile and may thus constitute a prolific source of contamination unless special precautions concerning the sanitary condition of equipment and of the air are observed.

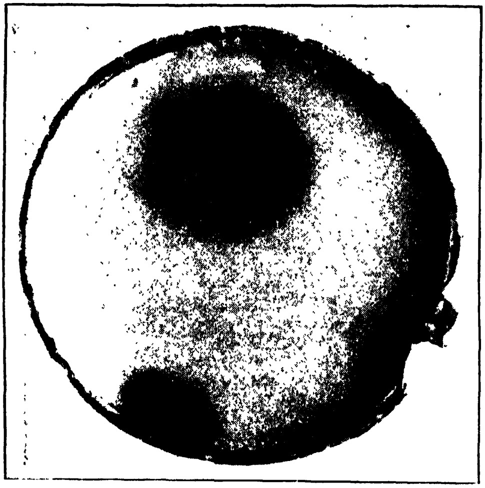


Fig. 107. Buttons in growing state, molds still very evident

Courtesy of L. A. Rogers, U. S. Bureau of Dairy Industry

In condenseries which use the continuous plan of cooling the product is protected against the atmosphere of the factory from the time it leaves the vacuum pan until it enters the tin cans, and if the cooling coils used in this system are kept clean and are steamed out thoroughly at least once each week, which is readily and quickly done with this type of equipment, contamination should be very largely eliminated and the appearance of buttons guarded against.

The empty tin cans in many of the plants are kept under undesirable conditions. They are exposed to diverse channels of contamination during transportation to the factory and during storage in the factory. If these contaminated cans are subsequently filled with the condensed milk, contamination is unavoidable and buttons are likely to follow.

The tin cans should therefore be protected against avoidable contamination, or better yet, they should be sterilized before filling. A practical sterilizer of empty tins may be readily devised by permitting the cans to pass inverted over a series of gas flames, under a hood. This method is used successfully in some of the European condenseries and has solved for them, in a large measure, the prevention of buttons as far as the can as a source of contamination is concerned. The caps and filling machines obviously should receive such treatment as to prevent them from becoming sources of contamination. Barrels should be steamed till piping hot and then paraffined or coated with silicate, before filling. The danger of mold contamination is far greater when the filling and sealing are done on wood floors, than when done on clean concrete or tile floors.

According to Thom and Ayres[183] the spores of the mold Aspergillus repens, as well as of most other common molds, are killed in 30 minutes at 140° F. The preheating of the milk in the hot wells, which is usually done at 167° F. or slightly above and again evaporation in the vacuum pan at 135 to 145° F., practically preclude the possibility of these molds surviving the process of manufacture, should they be present in the fresh milk. It, therefore, follows that their presence in the finished product is due to contamination of the condensed milk after it leaves the vacuum pan.

Low Temperature.—The growth of most molds is retarded, if not entirely inhibited at low temperatures. This also is the case with the button-forming mold Aspergillus repens. Rogers et al.,[163] state that this mold grows very poorly at temperatures of 68° F. or below. They report that they have never observed buttons on condensed milk held at 68° F. or below. These temperature limits are slightly at variance with the experimental results of Hunziker, and the experience of the manufacturer. In commercial manufacture, the storage of sweetened condensed milk at 68° F. will show button formation, if such milk contains button-forming spores. Reasonably sure prevention of buttons may be secured by holding the sweetened condensed milk at about 50° F. or below.

Exclusion of Oxygen.—Molds need air for their life and growth. They cannot develop in the absence of oxygen. Rogers et al., found that by sealing the cans under a vacuum of 20 inches or more, button-formation in condensed milk contaminated with button-forming molds could be entirely prevented.

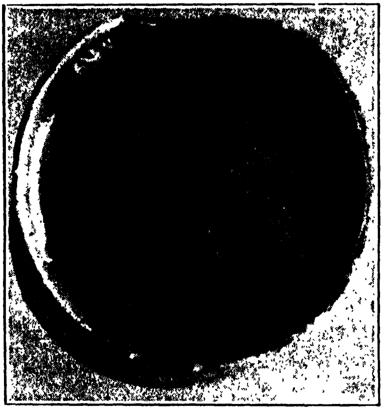


Fig. 108. Button development under atmospheric pressure

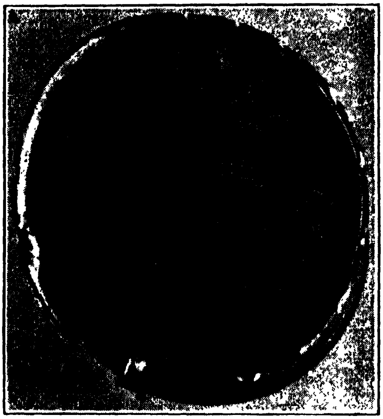


Fig. 109. Absence of buttons in 20 inch vacuum

Courtesy of L. A. Rogers, U. S. Bureau of Dairy Industry

GASEOUS FERMENTATION IN SWEETENED CONDENSED MILK

General Description.—One of the most disastrous troubles in the manufacture of sweetened condensed milk is the appearance of "swell heads" or "bloats." This term is applied to cans of condensed milk the contents of which have undergone gaseous fermentation, the resulting pressure causing the ends of the cans to bulge or swell, and frequently to burst open along the seams. In the case of barrel goods, the pressure may cause the barrel head to blow out. This gaseous fermentation is usually, though not always, accompanied by the development of acid and the formation of lumps.

This fermented milk is commercially worthless for any purpose and means a total loss to the manufacturer. The loss is generally augmented by the fact that this trouble does not become noticeable at once; its development requires several weeks, so that large quantities of condensed milk may have been manufactured before it is apparent that the milk is defective. Some of the goods may have reached the market before the cans begin to swell, in which case the reputation of the respective brand is jeopardized. In some instances entire batches show this defect, while in others only a few cans or cases of each batch are "blown."

Causes and Prevention.—In most cases this defect—bloats—is the result of profuse contamination of the milk with specific types of microorganisms, especially sucrose fermenting yeasts, that are capable of thriving in highly concentrated solutions of sucrose. The presence of large numbers of these fermenting organisms may be due to uncleanly production of the fresh milk; forewarming at too low temperature, or for too short a time to insure high germ-killing efficiency; heavy recontamination after condensing and before canning; insanitary condition of equipment, pipes and pumps; prolonged exposure of condensed milk to air before filling, encouraging invigoration of the germs already in the product; unclean tins and tins that are not air-tight; or impure or contaminated sugar. Insufficient concentration may serve as a contributing cause.

The tins may bulge also as the result of exposure, successively, to low and high temperature in the case of tins that are not completely air-tight, such as tins with solderless seals. In these instances the bulging is not due to microbial activity, it is caused by mechanical contraction and expansion; while the contents of such cans may be and usually are perfectly sound, the tins do not pass inspection because their distended ends give them the appearance of bloats.

Bloats due to Presence in Milk of Specific Gas-Producing Microorganisms.—Gaseous fermentation in sweetened condensed milk has been studied by many investigators; their findings are not altogether in agreement for numerous, more or less obvious reasons, such as variety of organisms capable of fermenting the product, extent of contamination necessary to produce the defect, state of invigoration of the organism responsible at the time of inspection, thoroughness of investigation and method used in efforts to reproduce the defect, as well as conclusions drawn in absence of sufficient experimental data.

Cassedebat,[184] who examined a number of blown tins, found no aerobes nor anaerobes in the contents, but observed some mold. He concluded that the bulging was due to chemical and physical causes but not to bacteria.

Dodge[185] reported the contents of blown tins discolored and darkened, of high acid and cheesy odor. He failed to find gas-producing organisms and could not reproduce gassy fermentation with organisms isolated from the bloats. He concluded that bacteria were not the cause of swells. Butyric acid solutions of 0.5 per cent strength and lactic acid solutions of 0.2 per cent strength when allowed to act on the metal of the tins caused slow evolution of gas. Because of these results this author suggested that the formation of gas in the unsound tins was not caused directly by bacteria but by electrolytic action between acids generated by bacteria in the milk before it was condensed and the metal of the cans.

Pethybridge[186] investigated a case of gassy fermentation in sweetened condensed milk in a condensery in Ireland and concluded that the fermentation was due to a budding yeast. He found small clots in the blown milk. He isolated two types of yeast that were capable of producing gassy fermentation when inoculated into tins of sound sweetened condensed milk. Bulging resulted in about six weeks after canning. The fermented milk was normal in color, had a faint alcoholic odor, but no "unpleasant" taste. The fermented milk contained 28.8 per cent milk solids not fat, 44.0 per cent sucrose and 27.2 per cent water. The yeasts isolated fermented saturated solutions of sucrose.

Cordes[187] studied the bacterial flora of numerous bloats of sweetened condensed milk. While some of the species of bacteria were capable of producing gas in 30 per cent sucrose concentration, none of the species isolated produced gassy fermentation in normal sweetened condensed milk. On the other hand most of the yeasts isolated from bloats, when propagated in pure culture in sucrose media and reinoculated into sound tins, produced characteristic bloats. The yeasts isolated varied somewhat in morphology, some resembling Torula lactis-condensi and others corresponded more nearly with Torula saccharalis. Some were large and oval, others small and spherical, still others long and narrow in contour. The cultural characteristics were not worked out in detail but cultures from all of these types of yeast were found to produce bloats. The number of yeast present in bloated sweetened condensed milk varied within wide limits ranging from 2950 to 2,300,000 cells per gram.

Hammer[188] investigated a case of gassy fermentation in sweetened condensed milk made by a condensery in Iowa, involving some ten batches of milk. The cans started swelling in 7 to 8 days after canning. Gas formation was vigorous and many of the cans burst open. The milk contained many gas bubbles even after releasing the pressure. It had a yeasty odor and flavor—not disagreeable. There was no evidence of putrefaction. Microscopic slides made directly from fermented cans showed a multitude of bacteria and yeast. Ordinary beef extract agar developed numerous colonies, the majority of which were bacteria (especially cocci). On 30 per cent sucrose agar plates the colonies were largely yeast, but also some cocci, probably of a type similar to the sucrose-resistant cocci observed by Rice and Downs[162] in their study of bacterial thickening of sweetened condensed milk. The yeast inoculated into bouillon containing sucrose in excess of saturation grew vigorously at 37° C. Normal cans of sweetened condensed milk, when inoculated with bouillon culture reproduced gassy fermentation of a character similar to that found in the original fermented cans, in the majority of cases. The source of the contamination was not definitely located.

This organism produced gas in sucrose, glucose and fructose, but did not grow in lactose bouillon. Along with gas formation it produced acid equivalent to from 2 to 3 per cent N acid. In sucrose bouillon it produced from 1.75 to 3.90 per cent alcohol. The greater amount was produced in 30 per cent sucrose bouillon and the lesser amount in 50 per cent sucrose bouillon. It showed no signs of growth when inoculated into ordinary milk. Microscopic study showed the organism to be a budding yeast, oval in form, 2.3 to 2.9 microns long and 1.2 to 1.8 microns wide, usually single or with single bud; no spore formation was observed; the organism stained readily and was Gram+. Hammer proposed the tentative name Torula lactis-condensi.

Rogers and Clemmer[189] report that they found an organism of the aerogenes type producing gas in sweetened condensed milk sometimes in quantities sufficient to burst the can. The condensed milk contained from 40 to 45 per cent sucrose.

They state that the temperature in the forewarmer was sufficient to destroy this organism, but that an inspection of the factory showed abundant opportunity for infection, particularly by flies, between the pan and the can-filling machine.

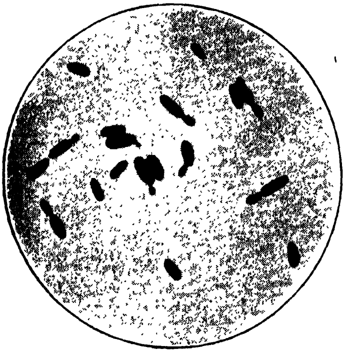


Fig. 110. Torula lactis condensi, from gassy sweetened condensed milk in barrels

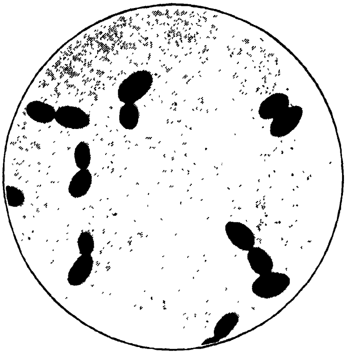


Fig. 111. Torula lactis condensi, from stock cultures after many transfers

Courtesy of B. W. Hammer

Savage and Hunwicke[190] made a most comprehensive study of the bacterial flora of 95 tins of sound and unsound sweetened condensed milk, of which 33 were found definitely blown. Reference to their research here is confined to their findings concerning blown tins only. These investigators found that the blowing of tins of sweetened condensed milk is almost invariably due to the growth and chemical action of yeasts, capable of fermenting highly concentrated solutions of sucrose. Their experiments clearly demonstrated, however, that the question whether tins become blown is not confined to the apparently simple question of the presence or absence of yeasts, and that, in fact, yeasts do not readily grow in sweetened condensed milk, partly because the condensed milk is not a medium particularly well suited to their growth, but chiefly on account of the restricted supply of oxygen.

The supply of oxygen in the tins is very limited and is soon exhausted. It is only when the yeasts are present in considerable numbers, or if they can multiply sufficiently in the presence of the oxygen supply available, that they are able to produce an adequate quantity of enzymes to break down the sucrose and produce gas. They are then comparatively independent of any oxygen supply. Their enzymes can continue to produce gas, without the necessity of a material increase in the number of yeast cells. For these reasons, if only a few fermenting yeasts gain access, gas production and the formation of bloats is unlikely. Their multiplication before anaerobic conditions become established in the tin, is too limited, and once the oxygen supply is exhausted, they cease to increase, and may gradually die out.

In commercial manufacture the appearance of bloats is confined largely to the summer months. This is in all probability attributable to the greater prevalence of yeasts and yeast contamination in summer than in winter, and to the greater opportunity for multiplication in warm weather while oxygen is still available. These observations emphasize the importance of canning the milk as soon as possible after cooling, in order to reduce to the minimum the time of access of the yeasts present in the condensed milk to oxygen.

The air-tightness of the tins is an additional factor that may assist in the prevention of bloats. Theoretically, the tins are considered air-tight, but experiments by the author have conclusively demonstrated that the non-solder seals are, in fact, not hermetically tight. In such cans a small supply of oxygen may be constantly available and this may be sufficient to become a contributing cause of fermentation and the development of bloats.

Savage and Hunwicke made a study of the distribution of yeasts from sources associated with condensed milk and its manufacture. Their findings are summarized below:

Table 41.—Distribution of Fermenting Yeasts

Material Examined	Number of Samples	Number Containing Yeasts	Percentage Containing Yeasts
Blown rejected tins	33	30	91
Rejected tins, but not blown	13	3	23
Sound shop samples	15	4	27
Sound freshly canned factory samples	25	14	61
Sound incubated factory samples	15	11	73
Ordinary fresh milk	12	9	75
Air of canneries, etc	8	8	100
Sugar used in making condensed milk	10	4	40
Deposit from pipes in canneries	2	2	100
All sources	133	85	65

Hunziker[191] had occasion to investigate numerous cases of this defect. In all cases that have come to his attention the condition of the contents of the bulged cans was very similar. Much pressure developed in the cans and many of the cans would burst open at their weakest point (usually along the body seam). The contents usually were rather fluid, gave off a distinct yeasty, sour odor and had a yeasty flavor. This flavor was not particularly disagreeable, but it was abnormal. Closer inspection of the milk generally showed some small lumps.

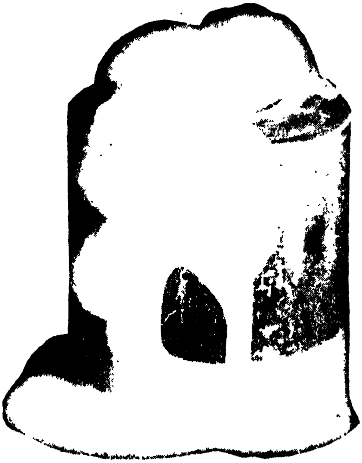


Fig. 112. Gassy fermentation in sweetened condensed milk

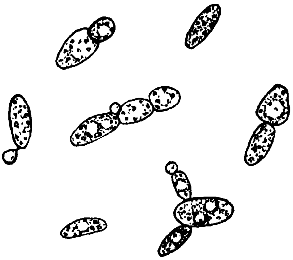


Fig. 113. Yeast cells causing gassy fermentation

Microscopic slides invariably revealed the presence of diverse species of bacteria and a goodly number of yeast cells; often the yeast cells were largely localized in and around the small lumps and were only sparingly found in the remainder of the milk in the tin. In no case was it possible to reproduce the fermented condition by inoculation of sound condensed milk with pure cultures of bacteria isolated from the fermented tins; but in the great majority of cases liberal seeding of normal condensed milk with pure cultures of yeasts from the fermented cans would cause the sound milk to develop the same gassy fermentation.

The yeasts responsible for the gassy fermentation appeared to be of the same general type. Microscopic examination showed them to consist of rather large, oval, budding cells, usually single or in groups of two or three cells, readily stained with ordinary stains. The contents of the cells had a granular appearance with one or two lighter bodies within, suggesting spores, as shown, by the accompanying camera lucida drawing. In all cases these yeasts were destroyed at temperatures below 180° F., suggesting that, if present in the raw milk they would not survive the usual forewarming temperatures employed in commercial manufacture.

In one epidemic of fermented sweetened condensed milk investigated by the author, the source of the infection was definitely located. It originated with the sugar. The sugar was supplied through a chute from the floor above, terminating over the hot well. The vapors arising from the hot milk condensed on the inside of the sugar chute, causing the sugar to stick to the sides and form a crust. This sugar crust in the chute attracted flies and wasps from the floor above, which probably contaminated it. The crust had turned to a light brown color. Inoculation of particles of this crust into concentrated sugar bouillon yielded violent fermentation with vigorous gas production. Microscopic slides showed a practically pure culture of the same type of yeast as was found in the fermented milk. Inoculation of tins of sound milk with crystals of this crust and with bouillon cultures of the same, respectively, produced swells at 80° F. in from one to two weeks. The contents of these bulged tins had the same appearance as the original fermented milk, and the yeasts found in the cans so inoculated were of the same type. Closing the sugar chute and supplying the sugar direct from the barrel stopped the defect immediately and completely. This yeast was capable of growing in a supersaturated solution of sucrose-whey bouillon containing 85 per cent sucrose.

Contamination with Yeast on the Farm.—In most cases of yeast fermentations of sweetened condensed milk, the source of contamination lies in the factory. While such contamination may and often does occur on the farm, the yeast cells, though they may be spore-bearing, are destroyed by the heat to which the fresh milk is subjected in the forewarmers and before it reaches the vacuum pan. The thermal death point of all forms of yeast which have come to the attention of the author in connection with a vast number of investigations of fermented condensed milk was below 180° F.

If, however, the forewarming temperature is limited to 145° F. or lower and the milk is not held at this temperature for about 30 minutes, or if the sugar or remnants of sweetened condensed milk are added to the milk before the full forewarming temperature has been reached, it is conceivable, though not probable, that yeast contained in the raw milk may reappear in the form of living cells in the condensed product in sufficient numbers to cause gassy fermentation.

Contamination with Yeast in the Factory.—As previously stated, yeast fermentation of condensed milk can almost invariably be traced back to contamination in the factory. After the milk leaves the forewarmers, or hot wells, it is never again heated to temperatures high enough to destroy these fermenting yeast cells. The channels through which yeast contamination may occur in the factory are many as shown in succeeding paragraphs.

Contaminated Sucrose.—The sucrose itself may be contaminated with fermenting yeasts. Yeasts have been isolated from the sugar by several investigators. However, if sugar of high quality is used, contamination of the sugar with sufficient number of fermenting organisms to be a cause of bloats, is remote.

Nevertheless, even the best quality of sugar may become the cause of fermented milk, if kept under such conditions as will favor its profuse infection. To permit the sugar in storage or elsewhere before it reaches the milk, to become damp is one of the surest means to invite bloats, as shown by the investigation of the author, previously cited.

Contaminated Equipment and Milk Conveyors.—The importance of scrupulous cleanliness of all equipment and pipes has already been dwelt on in a general way in Chapter III, under "Factory Sanitation." It is of special significance with regard to fermented sweetened condensed milk, because the sanitary status of the equipment between forewarmer and filling machine determines to no small degree the number of microbes found in the contents of the tins. It has already been shown that fermenting yeasts and other micro-organisms are found in most tins, sound as well as unsound. But in order to cause gaseous fermentation in so unfavorable a medium, the fermenting organisms must be present in large numbers. It is the accumulative effect of contamination of the milk in its contact with the large number of receptacles and conveyors used in the factory, together with the micro-organisms carried over from the fresh milk and the germs introduced by exposure to factory air, that jeopardizes its quality, quite as much as any one particular localized source of contamination.

The surest means of reducing to the lowest possible minimum this accumulative effect of contamination from factory equipment lies in scouring all parts that come in contact with the milk, condensed milk and the sugar after each day's use until the surfaces are clean, flushing out with plenty of hot water and steaming until the metal surfaces are "piping" hot, and flushing out and thoroughly steaming again all equipment and pipes the next morning, before the milk is permitted to circulate.

Contamination During Cooling and Holding Before Canning.—Cooling and holding the sweetened condensed milk in open cans or open tanks invites contamination from factory air, increasing the type and number of micro-organisms in the milk. Prolonged holding is seriously objectionable also because in the presence of air the yeasts that may be present will multiply rapidly and by the time the milk is sealed into the tins enough multiplication may have occurred to cause inversion of the sugar due to the enzyme invertase. In this condition fermentation is facilitated and the production of swells encouraged. The milk should be protected as much as possible from exposure to air during cooling and holding and it should be tinned or barrelled as soon as possible after cooling.

Contamination Through "Cut-opens."—It is customary to empty the contents of sample cans which are cut open for any purpose, back into the condensed milk of succeeding batches. If these samples happen to be contaminated with the fermenting germs, the defect is naturally propagated from batch to batch and it is exceedingly difficult to locate the source of the trouble. It is obvious that all suspicious "cut-opens" should be rejected and that all "cut-opens" that are utilized should be emptied into the hot well where their contents are "boiled up" again.

Dangerous Effect of High Acid in Milk.—Acids have the power of inverting sucrose. The inversion by acid is especially active in the presence of heat. The milk in the vacuum pan is condensing at 130 to 145° F. These temperatures are most favorable to inversion of a portion of the sucrose in the presence of acid. The higher the acid content of the milk, the more active is the inversion.

Contamination with Butyric Acid Bacteria.—Frequently the troublesome microbe is not a yeast, but belongs to a species of bacteria highly resistant to heat, and which fails to be destroyed by heating the milk to near the boiling point, such as organisms belonging to the butyric acid group of bacteria. The most prominent among these are Granulobacillus saccharobutyricus mobilis or Bacillus saccharo-butyricus, Bacillus esterificans, and Bacillus dimorphobutyricus. The putrefactive forms of butyric acid organisms, such as Bacillus putrificus, Plectridium foetidum, Plectridium novum, etc., do not seem to thrive in sweetened condensed milk.

The contamination may occur from dust of hay and other fodder, grain, bedding, or the unclean coat of the udder and surrounding portions of the animal, or from milking with wet and unclean hands, or from remnants of milk in unclean utensils.

It is noticeable that the great majority of cases of blown milk appear during late summer and early fall, when the crops are harvested and the air in the barn is frequently loaded with dust from the incoming crops. Gelatin plates exposed in the stable before and during the filling of silos showed an enormous increase of colonies on the plates exposed during the filling of the silos. Milk drawn under such conditions is naturally subjected to excessive contamination, unless special precautions are observed.

A very common source of these butyric acid organisms also is remnants of milk in pails, strainers, coolers, cans and any other utensils with which the milk may come in contact on the farm, also polluted water used in rinsing the utensils. The cheese-cloth strainer, owing to the fact that it is difficult to thoroughly clean and that it is seldom really clean, is a very serious menace in this respect. Under average farm conditions, unless a new cloth strainer is used at each milking, it is safe to condemn it entirely and to recommend the use of a fine wire mesh strainer containing about eighty meshes to the inch. On some farms the milk is held in a set of old cans which are kept on the farm and which never reach the can washer at the factory. Just before hauling time these cans are emptied into the clean cans from the factory. These old cans are often not washed properly and sometimes not at all. The remnants of milk in these cans breed these undesirable germs and contaminate the fresh milk. It is obvious that such a practice is bound to jeopardize the quality and life of the finished product and may constitute a continuous cause of blown milk.

While no cases have been reported where it was definitely established that butyric acid bacteria were the direct cause of gassy fermentation in sweetened condensed milk, their presence is highly undesirable. As previously shown, in most cases of gassy fermentation the condensed milk contained large numbers of bacteria, as well as yeasts. It is quite possible that some of these bacteria, including the butyric acid type, exert an effect additive to that of the yeasts, or favorable to yeast action.

Relation of Sucrose Concentration to Gaseous Fermentation.—The experimental results of several investigators, quoted in this chapter, show convincingly that certain species of fermenting yeasts that have been definitely proven to cause gaseous fermentation in this product, when other conditions are favorable, are capable of fermenting saturated solutions of sucrose. This fact is convincing evidence that bloats cannot be prevented by merely increasing the sucrose concentration. However, it has been further shown that at the higher sugar concentration, such as solutions containing 60 per cent sucrose or more in water, most of the fermenting yeasts are less vigorously active than in lower sugar concentrations.

Bloats Caused by Mechanical Contraction and Expansion of Milk in Tins.—The cans of sweetened condensed milk may also bulge in the case of cans with non-hermetical seals, exposed successively to excessive cold and to room temperature or summer heat. In this case, the condensed milk is entirely normal and unaffected, and the bulging is the result of mechanical contraction and expansion by cold and heat. This is possible only where the seal of the cans is not entirely hermetical. In the case of the Gebee seal with the burr cap, and the McDonald seal with the friction cap, the seal is not absolutely air-tight. While the pores between cap and can are microscopic in size, and not large enough to permit the viscous contents from leaking out, they are sufficient to admit air. The cans are usually filled with the condensed milk at a temperature of about 70° F. If the filled and sealed cans are exposed to a very low temperature, as may be the case in winter, in storehouses or in transit, the milk and the air in the cans contract. This contraction is intensified by the fact that the sweetened condensed milk does not freeze. This contraction of milk and air in the cans produces a partial vacuum, causing air to be drawn into the cans through the microscopic openings of the seal. When the cans are subsequently exposed to higher temperatures, the milk and the air in the cans expand, but the viscous milk forms a seal preventing the escape of the surplus air. The result is that the ends of the cans bulge. This phenomenon has been experimentally determined by the author.

A condensery using the Gebee type seal, see illustration in Chapter XI, stored its goods during the winter months in a shed where it was exposed to low temperature. When this milk was shipped out the weather was warm. Soon complaints were received that the milk was spoiled, the cans having become bloated. Tins sent to the author for examination showed the typical swelled ends of bloats, but the milk was perfectly normal. In order to definitely determine the cause, numerous tins were filled with a new batch of sweetened condensed milk into Gebee-sealed cans. An equal number of tins filled with portions of the same milk were sealed hermetically tight with solder. Both sets of cans were placed in the cooler at 40° F. and one-half dozen of Gebee-sealed cans and of solder-sealed cans that were purchased from grocery stores at random, were also placed in the same cooler.

At the end of three days all tins were brought into the office and placed on a top shelf where the temperature was approximately 80° F. After three days all tins were examined. Every tin with the Gebee-seal was bloated, the ends bulging out decidedly. Every tin with the solder-seal was normal, no bulging at the ends. Upon opening, the contents of all the tins were found perfectly normal.

It is evident, from the above data, that the swelling of the cans, as the result of exposure to excessively low temperatures and subsequent change to warmer surroundings, can readily be avoided, either by protecting the cans against excessive cold, or by using cans that are sealed with solder.

RANCID SWEETENED CONDENSED MILK

General Description.—Rancidity is not a frequent defect of sweetened condensed milk. When it does occur, however, the product usually becomes unfit as a food for any purpose.

Rancid sweetened condensed milk has the disagreeable flavor and odor characteristic of butyric acid, which becomes pronounced in advanced stages of the defect. Rancidity is the result of hydrolysis of the milk fat, brought about by fat-splitting bacteria, or fat-splitting enzymes secreted by certain species of micro-organisms, or by the presence of the enzyme lipase which is inherent in raw milk. The rancid flavor and odor are attributed to the liberation, by hydrolysis, of butyric acid and other fatty acids of low molecular weight.

It was shown by Orla-Jensen[285] and Kirchner[192] that certain species of micro-organisms, commonly present in butter, are capable of hydrolyzing the fat in butter to a marked degree and of developing in butter an intense rancid odor and flavor. To this class of organisms belong the fungi of Penicilium glaucum, Penicilium roqueforti, Cladosporium butyri, Oidium lactis, Actinomyces odorifora, several yeasts, and such bacterial species as Bact. fluorescens liquefaciens, B. prodigiosus, B. mesentericus. It is probable that the fat hydrolysis and the rancidity that is associated with these micro-organisms is due to fat-splitting enzymes which they produce, rather than to their direct action on the fat.

Relation of Polluted Water to Rancidity.—Polluted and filthy water is usually contaminated with fungi and bacteria belonging to the species enumerated above and which have been found to be able to produce rancidity. It is, therefore, not improbable, where such water is used in the factory in the washing of cans, conveyors, kettles, pipes, etc., in the condenser of the vacuum pan and in the cooling tanks, as is frequently the case, that the contamination of milk with it may result in the development of rancidity.

A specific case of sweetened condensed milk developing a rancid flavor and odor was brought to the attention of the author. The rancid taste developed in the course of 4 to 6 weeks after canning. Investigation showed that the condenser of the vacuum pan was completely coated on the inside with a thick and tough layer of milk remnants that had a most intensely foul odor, characteristic of cultures of Bacillus fluorescens liquefaciens, the usual inhabitant of polluted water. Examination of the water supply revealed the fact that the water used for condensing and elsewhere in the factory came from a creek badly polluted by slaughter house refuse. The use of artesian well water in the place of creek water and the thorough cleaning out of the condenser stopped this defect.

Relation of Incomplete Forewarming to Rancidity.—Raw milk contains the fat-splitting enzyme lipase. If this enzyme is not destroyed in the process of forewarming, it passes into the finished product and causes the condensed milk to become rancid. Rancidity in sweetened condensed milk is usually, though not always, accompanied by increase in acidity and thickening of the product.

Rice[36] demonstrated that low forewarming temperatures (140° F. 15 minutes or 150° F. flash) were insufficient to destroy the lipase when sugar (sucrose) was present in the milk. He further found that the addition of as little as .75 per cent of unheated milk to normal condensed milk was sufficient to always produce rancidity.

The results of Rice suggest the following precautions to prevent rancidity in sweetened condensed milk:

1. Avoid contamination of the heated milk with raw milk. Such contamination is most likely to occur in the presence of leaky valves between hot wells, or accidental drawing into the pan of unheated, or insufficiently heated milk, or the addition to the heated milk in the hot well of remnants of unheated skimmilk, milk, or cream at the time of emptying the hot well into the pan.

2. Use forewarming temperatures sufficiently high to insure the destruction of the lipase. In the absence of sucrose, forewarming to 167° F. to 170° F. for 10 minutes insures complete destruction of the enzyme. The presence of sucrose increases its resistance to heat. It is important therefore that the milk be heated to the full forewarming temperature before the sugar or remnants of condensed milk are added.

TALLOWY FLAVOR IN SWEETENED CONDENSED MILK

General Description.—The flavor of tallowy sweetened condensed milk, similar to that of tallowy butter, studied by Hunziker and Hosman,[4] and of tallowy whole milk powder discussed by Supplee[193] and Holm and Greenbank,[194] resembles that of mutton tallow. The tallowy flavor and odor of sweetened condensed milk are defects much less prevalent than rancidity and usually less pronounced than in tallowy butter.

Tallowiness in sweetened condensed milk is usually accompanied by bleaching of color, but not by increase in bacteria, acidity or thickening. It is due to a partial breaking down of the milk fat, but unlike rancidity, which is the result of hydrolysis due to microbic and enzymic activity, tallowiness is caused by oxidation. Tallowiness is the result of chemical changes. It is not caused by biological activity. However, as shown by Rice,[36] free fatty acids (which are the result of hydrolysis brought about by bacterial or enzyme action) may catalyze the reaction involved in the development of tallowiness. Thus biological agencies, particularly enzymes, may cause indirectly, or hasten, the chemical action leading to tallowiness.

Effect of Air and Light on Tallowiness.—When a can of normal sweetened condensed milk is opened and exposed to air and light a tallowy flavor develops rapidly on its surface. The crust that forms on its surface due to evaporation usually is intensely tallowy. The cause here lies in the oxidizing action of the air on the butterfat, which is intensified in the presence of direct sunlight. Prolonged holding of the finished product, before packing, in open tanks, forewarmers and the like, invites oxidation and tallowiness. This tendency is increased in the presence of copper. Air space in the sealed tins, due to incomplete filling, encourages the development of tallowiness. The tendency for this defect to appear is therefore minimized by avoiding excessive exposure to air in the factory and by so gauging the filling of the tins as to reduce the air space in them to the minimum.

Effect of Metals on Tallowiness.—Hunziker and Hosman[4] and Hunziker, Cordes and Nissen[7] showed that copper, being an oxygen carrier with intense catalytic powers, readily oxidizes butterfat and is capable of catalyzing the oxidizing action of the air, causing the butterfat to bleach and become intensely tallowy. The same is true of the alloys containing copper such as nickel silver and similar alloys, though the action here is more gradual. Iron, zinc and galvanized iron, likewise, are capable of producing tallowiness but to a lesser degree than copper. Tin, aluminum, nickel and chrome-nickel steels do not cause this defect.

Much of the equipment used in the milk condensery is constructed of copper. This refers to the hot wells, vacuum pans and similar equipment. The use of metals other than bare copper and copper alloys for the surfaces coming in contact with milk and condensed milk is therefore advisable. If copper equipment must be used, it is important to avoid holding the product in such equipment unnecessarily long.

The condition of the copper surface is an important factor in determining the amount of copper contamination of the milk. Freshly scoured surfaces that are bright and shining reduce contamination of the milk with damaging copper salts to the minimum. This fact emphasizes the importance of daily scouring of all copper surfaces in hot wells, vacuum pans and the like. In case equipment has been lying idle for some time it should be scoured again before use or a batch of water should be circulated through it, operating the equipment in a similar manner as with milk, or both.

Special attention should be given to the condition of the top portion of the pan, the dome, and goose neck and internal condenser. This is often neglected in the routine of pan washing, causing these parts to become prolific sources of copper contamination. The sugar and acid of the milk spray coat the upper parts of the pan and if the film of this material is not daily removed, copper salts and oxides readily form between operating days. These metal compounds are automatically rinsed down by the milk spray of the next day's run, causing copious copper contamination, giving the condensed milk a disagreeable, metallic, coppery taste, and inviting the development of tallowy flavor, if other conditions (such as air supply) are favorable.

Rice,[195] who studied the causes of tallowy sweetened condensed milk, demonstrated experimentally that even excessive exposure to air did not produce tallowiness in sweetened condensed milk prepared in glass equipment (in the absence of copper), while check batches in which copper salts were present always developed the tallowy flavor. Rice further reports that condensed skimmilk (which always contains a small amount of milk fat) may become slightly tallowy, but to a much less degree than condensed whole milk under the same conditions. See also Chapter II on "Metals in Dairy Equipment."

METALLIC SWEETENED CONDENSED MILK

General Description.—Sweetened condensed milk not infrequently is pregnant with a pronounced, disagreeable metallic flavor suggesting the puckery, coppery taste of copper salts.

Causes and Prevention.—This is usually traceable to the use of copper equipment, the milk surfaces of which are not scoured properly, have become tarnished and show accumulations of copper corrosion. See also "Tallowy Flavor." Sweetened condensed milk made in nickel or chrome-nickel steel equipment is entirely free from this defect. Likewise, the product of factories which give proper attention to the cleansing routine of copper equipment are seldom troubled with this defect.

Metallic flavor in sweetened condensed milk may also appear in milk condensed in the "Continuous Concentrator," when the scraping edges of the rapidly revolving agitator are set too close to the copper shell. In such case there is a tendency for fine copper particles to be mechanically shaved off the inside wall of the concentrator and incorporated in the finished product. The proper adjustment of the metal scrapers, or preferably, the substitution of the metal scrapers with wooden scrapers eliminates this danger.

BROWN DISCOLORATION OF SWEETENED CONDENSED MILK

General Description.—This defect has to do with discoloration that causes the creamy yellow color of normal, fresh, sweetened condensed milk to darken to diverse shades of brown, which in extreme cases may resemble the color of chocolate.

Age Discoloration.—The brown discoloration of sweetened condensed milk is principally, though not always, an age defect, that is readily prevented by holding the product at a reasonably low temperature. Storage at temperatures below 70° F. retards the discoloration, and below 45° F. the product retains its normal color indefinitely. Above room temperature the darkening becomes very definite; the rapidity of change and the intensity of brown discoloration increasing rapidly as the temperature rises.

Effect of Process of Manufacture on Brown Discoloration.—The forewarming temperature does not noticeably affect the color of the finished product while fresh. However, there is a tendency for high forewarming temperature (180° F. and above) to somewhat intensify the brown discoloration during storage at the higher storage temperatures.

The addition to the milk in the forewarmer of remnants of condensed milk and the recondensing of sweetened condensed milk have a very pronounced darkening effect on the color of the finished product.

Since neither sucrose nor lactose is capable of caramelizing at temperatures below the boiling point of water, the earlier conception that the reactions involved in the brown discoloration of sweetened condensed milk deal with oxidation and caramelization of the sugar contained in the condensed milk (either the lactose or the sucrose, or both) is no longer tenable. It appears from recent work of several investigators that reducing sugars such as lactose and dextrose, when in the milk in the presence of heat react with the milk proteins, particularly with certain amino-acid groups of the casein. This interaction yields amino-acids-sugar complexes which themselves show a pronounced brown discoloration, and the presence of which in the milk changes the color of the milk.

The progressive age darkening in high temperature storage may be explained by the assumption that interaction between lactose and proteins is incited during manufacture in the presence of the heat of forewarming and condensing, and that it proceeds after manufacture to the point of discoloration at the higher storage temperatures.

The above theory is strengthened by the finding of Ramsey, Tracy and Ruehe[46] who showed that in the presence of dextrose the interaction is so intense that, in order to prevent the dark discoloration from appearing immediately after manufacture, it is necessary to forewarm the milk and the sugar separately and draw the sugar syrup into the pan only toward the end of the condensing process.

The sucrose appears not to be involved in this interaction, but may become a factor in the brown discoloration as the result of subsequent inversion, such as might be brought about in the presence of high acidity or enzyme action, or both. For details see Chapter XXIII on "Color of Milk."

FAT SEPARATION IN SWEETENED CONDENSED MILK

General Description.—The creaming off of sweetened condensed milk is a rare occurrence. When it does happen a whitish to deep yellow layer of what looks like almost pure butterfat usually floats on the surface. It mixes into the contents readily by stirring or shaking.

Causes and Prevention.—In commercial manufacture fat separation in sweetened condensed milk is confined almost exclusively to insufficient concentration of the milk. Under-concentration readily causes fat separation and the defect is aggravated by exposure to relatively high storage temperature. In short, fat separation here is principally due to abnormally low viscosity. The milk is too thin.

For similar reasons fat separation may and does also occur when forewarming at unusually low temperature, even when the degree of concentration is sufficient to produce a condensed milk of standard composition. The lower the forewarming temperature, other factors being equal, the lower the viscosity and the thinner the milk. This was demonstrated experimentally by Rogers, Deysher and Evans[64] in the case of sweetened condensed milk condensed to 28 per cent milk solids and a sucrose-in-water concentration of 60 per cent. (This milk contained 43.2% sucrose.) The milk had been forewarmed at 145.4° F. The finished product developed slight but noticeable fat separation when stored at 86° F. Milk of the same concentration but forewarmed at 203° F. suffered no fat separation. Fat separation in the low-forewarmed milk was prevented by homogenizing at 3,000 pounds pressure.

Condensing to the proper degree of concentration and forewarming at temperatures not lower than 165° F. to 170° F. are dependable safeguards against fat separation in sweetened condensed milk, without the aid of the homogenizer.

CHAPTER XXVI.

DEFECTIVE EVAPORATED MILK

Evaporated milk of superior quality is homogeneous in consistency, has a full smooth body and a light, creamy color, is free from off-flavors and devoid of all symptoms of fermentation. The most common defects which this product may show are curdiness, bloats, bitter flavor, grainy sediment, fat separation, brown discoloration.

CURDY EVAPORATED MILK

General Description.—The curdy condition may consist of a solid clot or coagulum, or it may occur in the form of flakes or lumps of curd. It may or may not be accompanied by the separation of whey.

The presence of curd in the tin upon removal from the sterilizer is usually due to heat coagulation difficulties. The formation of curdiness after manufacture is generally traceable to biological activity resulting from incomplete sterilization or defective tins.

Curdiness Due to Heat Coagulation.—A coagulum forms during the sterilizing process in most of the batches. This jell may be so soft that the agitation the milk receives in the sterilizer is sufficient to cause it to break down, disappear and yield a product entirely smooth by the time the sterilizing and cooling is completed. This is in fact the intention and usually the result of sterilization in the continuous sterilizer in which the tins are in continuous rolling motion until they leave the machine.

Batches in which the curd is still visible to the eye when the cans escape from the sterilizer may be readily reduced to a smooth, homogeneous body by placing them into the shaker, provided the curd has a soft and loose texture. If the heat coagulation has reached the point, however, where the curd has become much contracted, tough and firm, it may fail to respond to the shaking process satisfactorily, resulting in a permanent curdy condition of the milk.

It is of great importance, therefore, to so co-ordinate the heat coagulation point of the milk and the temperature and duration of sterilization as to accomplish complete sterilization before and without the formation of a permanent curd. The factors that determine heat coagulation and the presence or absence of a permanent curd in evaporated milk are freshness, quality and acid reaction of the fluid milk, the salt balance and its relation to the hydrogen ion concentration, the temperature of forewarming, concentration of milk solids and pressure of homogenization, and the heat treatment of sterilization. These factors are discussed in detail in Chapter XV.

Effect of Condensing in the Continuous Concentrator.—Some condenseries operate milk receiving stations at which the milk is condensed in the continuous concentrator to a rather high degree of concentration. This concentrated milk is then shipped to the condensery where it is mixed with fluid milk and run through the pan. Evaporated milk made in this manner may not develop a permanent curd in the sterilizer but it may develop incipient curdling or thickening upon standing. The same is true also when the entire batch is condensed by the use of the continuous concentrator.

The exact cause of this curdling is not well understood, but experience and observation suggest that either the high concentration or the high temperature to which that portion which was condensed in the continuous concentrator was exposed, or both, are responsible for this phenomenon. Experience in the manufacture of evaporated milk, in which all of the milk is condensed in the continuous concentrator, has demonstrated that after sterilization the product has a tendency to thicken. In some cases under observation it turned completely solid.

Acid Flux in the Cans Causes Lumps.—Similarly as in the case of the sweetened condensed milk, the presence of acid flux in the cans of evaporated milk causes lumpiness. The acid that reaches the interior of the cans causes the milk coming in contact with the seams to curdle. Only acid-free flux should be used in the manufacture and sealing of the cans.

CURDINESS DUE TO BACTERIA

General Description.—Numerous reports are on record of bacterial study of evaporated milk that appeared to be sound after the usual period of incubation but developed a more or less curdy condition later, and that was found to contain bacteria capable of reproducing curdiness when inoculated into sound tins. These data suggest that there is a variety of micro-organisms capable of curdling evaporated milk and that their cultural characteristics and reactions in evaporated milk are often at variance with the changes they bring about in fluid whole milk and fluid skimmilk. Likewise, the changes which accompany the curdling action in evaporated milk vary with the specific organism. The curdling may or may not be accompanied by acid production, it may or may not lead to peptonization, to increase in volatile acidity, to the appearance of off-flavors and to changes in color and in viscosity.

In the case of some outbreaks of this nature the entire batch appeared to be involved, suggesting either too low a sterilizing temperature or abnormally great resistance to heat. In others, only a limited number of cases or cans showed the defect, suggesting uneven distribution of heat in the sterilizer or limited distribution of the organism. In the majority of cases the defect failed to show itself for many weeks after manufacture, suggesting abnormally slow growth, perhaps because of the relatively high concentration of milk solids, or of unfavorable storage temperatures which, when changed to higher temperatures, expedited the growth of the particular organisms involved.

Curdled Evaporated Milk Without Increase in Acidity.—Hammer and Hussong[196] investigated an outbreak of curdy evaporated milk that occurred during hot summer weather and isolated a spore-forming bacillus capable of curdling evaporated milk. The condition of the contents of the cans ranged from a few small masses of curd in some cans to a complete coagulation of firm or soft curd in others. There was no wheying-off. This organism did not change the flavor, odor or acidity of the milk upon short incubation at 37° F., but upon prolonged incubation at this temperature caused pronounced change in odor, flavor and color. They identified the organism as Bacillus cereus. A similar organism, an atypical B. cereus isolated from curdled evaporated milk was also reported by Kelly.[197] An outbreak of curdy milk during summer was studied by Hunziker and Wright.[198] The organism responsible was a small bacillus that completely curdled the evaporated milk without increasing the acidity, but which yielded an intensely bitter flavor. For details see "Bitter Evaporated Milk."

Sour, Curdled Evaporated Milk.—In the majority of the outbreaks of curdy evaporated milk the curdy milk is sour and the contents are more or less wheyed-off. Spoils of this type are readily detected by the characteristic thumping sound and "feel" when shaking the tins in the hand. Upon opening the tins, a more or less firm coagulum is usually found and the taste and odor are sour. Outbreaks of sour, curdy evaporated milk are most prevalent during the hot summer months.

Hammer[199] reported a case of sour, curdy, evaporated milk. The spoils upon opening had a firm curd and there was separation of a small amount of whey. In a few cans the coagulated material was flaky. The flavor and odor were faintly sour and slightly cheesy, but not disagreeable. The acidity ranged from .94 per cent to 1.14 per cent acid, calculated as lactic acid. The micro-organism causing this defect was inoculated in sound tins and when incubated at 55° C. (131° F.) coagulated the milk in 4 to 6 days, at 37° C. (98.6° F.) in 9 to 14 days and at room temperature in 19 days. It curdled milk with slight expression of whey but no digestion.

Hammer proposed the name B. coagulans. Old cultures showed organisms that have the appearance of containing

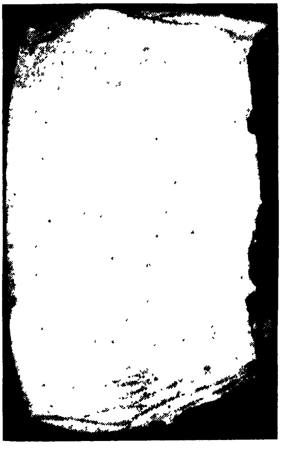


Fig. 114. Sour curd in evaporated milk

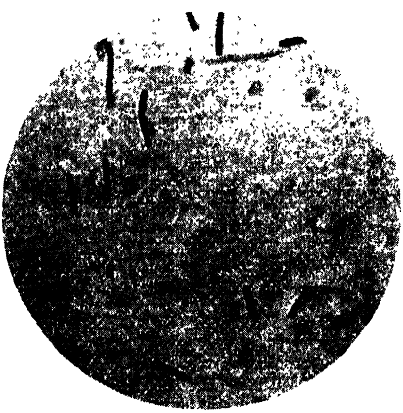


Fig. 115. B. Coagulans

Courtesy of B. W. Hammer

spores although the spores were not "real distinct." Milk cultures grown nine days at 37° C. resisted 80° C. (176° F.) for 10 minutes. The source of the contamination of the milk with B. coagulans was not located. But the description of the organism suggests that the cause of the specific case of sour, curdy evaporated milk was incomplete or non-uniform sterilization.

In a more recent outbreak (1930) of sour, curdy milk investigated by Sarles and Hammer[200] B. coagulans was again found to be the cause. The condensery in question produced defective milk of this type over a period of several weeks and there was considerable spoilage, even with a sterilizing process of 244° F. for 15 minutes, after raising the temperature in the first preheater heater for 12 minutes to 208° F. and holding it in the variable preheater at 208° F. for 12 minutes. The typical spoiled milk was firmly curdled but there were some cans with less complete coagulation. The odor and flavor were cheesy and sour but not suggestive of putrefaction. The total acidity ranged from .86 to 1.30 per cent., calculated as lactic acid. The volatile acidity had also greatly increased, showing values of 22 to 40 as against a value of 6 on normal milk. There was a marked increase also in both soluble nitrogen and in amino nitrogen in the spoiled milk. At an incubation temperature of 7 and 21° C. (44.6 and 69.8°F.), respectively, the inoculated cans failed to coagulate in four months. At 37 and 50° C., (98.6 and 122° F.), the inoculated cans coagulated in 3 to 10 days and 3 to 4 days, respectively. These findings emphasize the influence of storage temperatures and suggest that evaporated milk containing this organism may fail to show spoilage when storing at comparatively low temperatures.

Hunziker and Cordes[201] studied a case of sour, curdled, evaporated milk from which they isolated a bacillus that corresponded with Hammer's description of B. coagulans. Two factory tins with this defect were examined. The contents were a mass of irregular lumps of curd. The cans having traveled a long distance from factory to laboratory suggested that there was originally a smooth coagulum which broke up in transportation. There was no separation of whey. The milk had a slightly bitter, mildly acid taste of a cheesy character, not unpleasant. There was no evidence of gas.

Plate counts showed one can to contain 9,100,000 and the other 75,000 bacteria per cc. There was a great predominance of B. coagulans. Inoculated into sterile skimmilk and incubated at 37° C. it produced a soft curd, coagulation beginning at the bottom in two days. Inoculated into sound tins of evaporated milk and incubated at 37° C., in ten days it produced a soft curd with the characteristic, slightly sour and mildly bitter taste and cheese-odor found in the original spoils. The acidity ranged from .86 to 1.50 per cent in the different tins. Upon prolonged incubation clear whey appeared on top. The organism was not destroyed at 80° C. for 10 minutes, but failed to survive a temperature of 112.2° C. (234° F.), the culture itself reaching 234° F. and the time being 7 minutes from 212 to 234° F. This factory used relatively low temperatures for sterilizing and reported that portions of batches only showed this defect. This suggested uneven heat distribution in the sterilizer, see Chapter XIV.

In an investigation of sour, curdled evaporated milk produced in two separate condenseries. Hussong and Hammer[202] found the troublesome organism to be Bacillus calidolactis, a spore-forming facultative aerobe which grows and curdles the evaporated milk rapidly at from 55 to 60° C. (131 to 140° F.). The milk showed an acidity of .67 to .74 per cent, calculated as lactic acid. This thermophil failed to grow and did not curdle the milk at 37° C. (98.6° F.) or below.

These several citations of outbreaks of sour, curdled evaporated milk suggest that the organisms responsible are highly heat resistant and may, therefore, withstand sterilizing temperatures that are adequate to destroy the usual germ life present in evaporated milk. These observations emphasize the importance of greater attention to sanitation and scrupulous cleanliness in the factory to the end that the presence of these organisms may be avoided as much as possible. They further emphasize the advisability of using relatively high sterilizing temperatures and the importance of uniform heat distribution in the sterilizer, in order to insure maximum germ killing efficiency.

The fact that most of these organisms are of thermophilic tendencies assists in explaining the commercial experience and experimental observation that outbreaks of sour, curdy evaporated milk are largely confined to the summer season. The growth and action of these bacteria at ordinary temperature appear to be so slow as to suggest that their presence in evaporated milk held at these lower temperatures may not cause spoilage, while at summer heat, cans so contaminated will spoil rapidly.

GASEOUS FERMENTATION IN EVAPORATED MILK (BLOATS)

General Description.—The ends of the cans bulge out very noticeably, frequently so much so that the seams of the cans burst open. This is due to gaseous fermentation causing high pressure in the cans. The pressure is often so great that upon opening the cans, most of the contents are blown out with tremendous force. In some cases of blown evaporated milk, the contents have an acid odor, pleasant and aromatic. In most instances, however, they give off very foul odors, suggesting hydrogen sulfide and putrefactive decomposition. These odors are exceedingly penetrating and difficult to remove from anything they come in contact with.

Causes and Prevention.—Several different types of gassy fermentation causing bloats have been studied. Savage and Hunwicke[203] isolated several aerobic species of the B. coli group which caused gas production when inoculated into sound tins and they consider these organisms as definite causes of unsoundness and gas development in tins of evaporated milk. They also isolated coccoidal bacilli, micrococci, streptococci and a yeast capable of causing gassy fermentation. These investigators further report that the acidity in nine blown tins examined ranged from .45 per cent to 1.46 per cent as against .3 to .41 per cent in 24 samples of sound tins.

They also isolated anaerobic sporing bacilli from unsound bloated tins. Incubation of sound tins after inoculation with cultures of the anaerobes reproduced the characteristic gaseous fermentation, accompanied by increase in acidity at first and later decomposition and putrid odor. They observed that when spores only were inoculated, they did not always multiply or cause changes in the milk, but that if the spores can grow, which in some cases they did, they will decompose the milk. Savage and Hunwicke suggest that probably the presence of other organisms is of assistance. The two types of anaerobic sporing bacilli which they found in bloats and which reproduced the bloating in sound tins were B. putrificus and the Rauschbrand bacillus.

A gas producing streptococcus was isolated from a bloat of evaporated milk by Hammer[204] who suggested the name streptococcus disdendens. This micro-organism produced gas in evaporated milk regularly and within a wide range of temperatures. At 37° C. (98.6° F.) bulging occurred within 36 to 48 hours. At room temperature the tins started bulging in 72 hours. The evaporated milk had a sour and slightly bitter taste. The titratable acidity was 0.7 to 0.8%, calculated as lactic acid, and there was considerable volatile acid produced. No definite curd formation was observed, other than a small amount of curd along the walls of the cans in some instances. Evaporated milk fermented by this organism showed unusually large numbers of bacteria. At 37° C. for two days the plate count was as high as 600,000,000 to 800,000,000, and for eight hours over one and one-half billion per cc. S. disdendens is a facultative organism as to oxygen requirements and did not survive a temperature of 60° C. for 15 minutes. Its lack of resistance to heat and the fact that the original bloats contained other non-sporing organisms suggest contamination of the tin after sterilization through defective cans. The batch from which this bloat was taken contained but few spoils.

The cases of bloats above discussed appear to refer to isolated instances of swells of individual cans, rather than the "going wrong" of entire batches. The characteristic epidemics of bloats in commercial manufacture of evaporated milk, that involve the great majority of serious outbreaks of gaseous fermentation are caused by organisms of great resistance to heat. Such fermentations are usually due to anaerobic bacteria, belonging to the butyric acid group, and in most cases, though not always, the putrefactive types prevail. The more prevalent among these are Bacillus putrificus, Plectridium novum and Plectridium foetidum.

In a few cases of bloat investigated by the author, putrefaction was absent and gas formation was accompanied by high acidity and a not unpleasant, somewhat aromatic odor, the milk showing a flocculent curd. But the usual type of bloats had to do with intense putrefactive changes accompanied by violent gas production and the presence of foul odor. In every one of these cases the organism responsible for the fermentation was Plectridium foetidum.

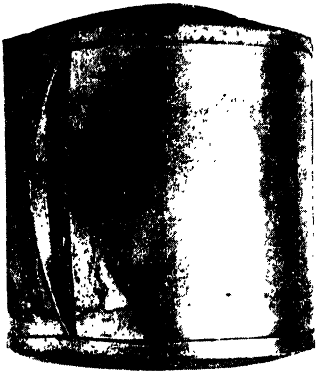


Fig. 116. Gassy fermentation in evaporated milk

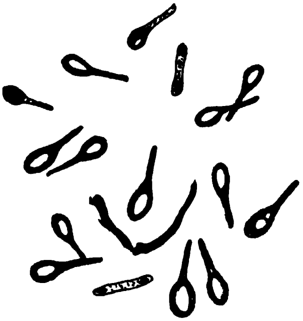


Fig. 117. Plectridium fœtidum, responsible for evaporated milk bloats

Plectridium foetidum is an obligatory anaerobe, it absolutely refuses to grow under aerobic conditions. It is an actively motile, medium-sized organism with flagella and spores. At one end it has an Indian club-like enlargement, in which appears the spore. The bacillus resembles a kettle-drum stick similar to B. tetani. Under strictly anaerobic conditions, and incubated at 90° F., it ferments milk in four days. The milk first curdles, then gradually the curd dissolves (digests) completely, leaving a clear yellow liquid, similar in appearance to butter oil. The fermentation is accompanied by the evolution of a penetrating foul odor. This organism survives exposure for 15 minutes to 245° F. Its thermal death point lies between 245 and 250° F.

Plectridium foetidum, as well as most of the other species of anaerobic, spore-bearing butyric acid bacilli and bacteria, is present abundantly in cultivated soil, in field crops and even on the kernels of the grain. Since this type of evaporated milk defect is characteristic, especially, of the product manufactured during the late summer and early fall months, it is not improbable that the dust incident to the harvesting of the field crops, furnishes the chief source of contamination of the milk on the farm, though it is quite possible that contamination with these germs may also result from the use of unclean equipment in the factory.

In order to avoid the occurrence of blown, fermented, evaporated milk, therefore, it is necessary to employ the highest sterilizing temperatures, or the longest exposure to the sterilizing heat, or both, consistent with freedom of the milk from curdiness. Experience has shown that the use of the ranges of temperature and time of exposure, given under Chapter XIV on "Sterilizing," guard effectively against this defect.

Bloats of Evaporated Milk Due to Freezing.—If the evaporated milk is exposed to storage temperatures below the freezing point of water, the contents of the cans will freeze. While freezing, the contents expand sufficiently to cause the end of the cans to bulge. When the cans are subsequently transferred to warmer temperatures, so that their contents melt again, the milk contracts and the cans resume their normal shape.

While the wholesomeness and flavor of the product are not affected by the freezing process, the remelted evaporated milk is usually less smooth and often slightly grainy. This is due to the fact that, during the process of freezing, there is a partial separation of the watery portion from the caseous material. The casein contracts and the watery portion freezes. When melted, the emulsion is less complete than it was before freezing. The casein appears to remain in this contracted condition and robs the product of its original smoothness. The emulsion and smoothness may be restored by subjecting such milk to the shaking process.

Bloats of Evaporated Milk Due to Chemical Action.—There is a possibility that tins of perfectly sterile milk upon prolonged aging may bulge, as the result of the action of the acid in the milk on the container. Evaporated milk contains from .35 to .50 per cent acid (calculated as lactic acid). When the tin cans are filled with the evaporated milk, the tinplate is bright and untarnished both inside and out. After the sterilizing process, the inside surface of the cans is dull and tarnished. This is caused by the combined action of acid and heat, which seems to weaken the tinplate. This phenomenon is further illustrated by the fact that where creameries pasteurize their skimmilk and return it to the patrons in the milk cans hot, the milk cans are short-lived; they soon corrode and begin to leak.

The acid in the evaporated milk continues to act on the tinplate of the can after manufacture and in the case of very old evaporated milk, the acid may decompose a considerable part of the iron. This action is accompanied by the evolution of hydrogen gas. It is hastened by continued exposure of the goods to high temperatures (summer heat). This fact was experimentally demonstrated by Hunziker[205] by scratching the bottom of tin cans on the inside with a file, then filling the cans with a .4 per cent solution of lactic acid and acetic acid, respectively. After sealing, the cans were sterilized in the autoclave, so as to avoid any possibility of bacterial action. After cooling, these sterilized cans were incubated for some time at 90° F. The cans containing the dilute acid began to swell, while the check cans, containing distilled water only, remained normal.

Dodge[185] also found that the action of a 0.5 per cent solution of butyric acid and a 0.2 per cent solution of lactic acid on the metal of the tin caused slow evolution of gas. Savage and Hunwicke,[203] however, putting lactic acid into the milk to bring the total acidity to .68 per cent and incubating the milk for a prolonged period could detect no gas formation and they concluded on the basis of their experiments that it is very unlikely that tins of evaporated milk ever become blown through chemical means alone.

Bloats of Evaporated Milk Due to Change in Altitude.—Cans of evaporated milk when filled in factories located at a low altitude (near the sea level) may bulge when transferred to a high altitude. The danger from this source is intensified, if the evaporated milk happens to be cold at the time of filling, and when the temperature to which the cans are exposed at the high altitude is high.

This type of swelled cans obviously has nothing to do with the quality of the contents, nor is it the result of fermentation or chemical changes. It is caused by the fact that the pressure in a can sealed at the sea level is somewhat greater than the atmospheric pressure surrounding the can when transferred to a high altitude. If, at the same time, the milk packed at the sea level goes into the can at a low temperature and the atmospheric temperature at the high altitude to which the sealed cans are shipped happens to be high, the difference in pressure between the interior and exterior of the can is further increased, due to the expansion of the milk and of the air in the can. The combination of these factors may be sufficient to cause the ends of the can to bulge, making it erroneously appear that the package contains fermented goods.

This has actually happened in the case of one factory filling a Government contract during the world war, the whole shipment of evaporated milk being rejected by the Government, because of the bulged cans. These goods, upon subsequent inspection of the contents of the tins, were found to be perfectly sound.

Occurrences of this type may readily be prevented by filling cans, intended for markets in high altitudes, with the evaporated milk while warm.

BITTER EVAPORATED MILK

General Description.—The appearance of a bitter flavor in evaporated milk is usually, but not always, accompanied by curd formation. Outbreaks of bitterness have been studied by several investigators. In some instances the bitter flavor was very intense. While not of common occurrence, this defect has been reported in several instances.

Outbreaks of Bitter Flavor.—Hunziker and Wright[198] investigated an outbreak of bitter flavor. The defective cans showed a solid coagulum, noticeably white in color and very bitter to taste, similar to the bitterness of dandelions. The curd was very firm and refused to break down readily upon shaking. The contents had wheyed off, there being a separation of practically clear whey. There was no increase in total acidity. The mixture of curd and whey showed a titratable acidity of .35 to .40 per cent calculated as lactic acid.

Cultures in sterile milk showed the presence of very small rods. There was apparently no spore-formation. The organism developed under both aerobic and anaerobic conditions, but preferred anaerobic conditions. It grew best at 90° F., forming a firm coagulum in five to seven days. In cultures over a week old the curd had an intensely bitter flavor, the same as that observed in the defective cans. The bitterness increased in intensity with age. Exposures to 212° F. for 15 minutes destroyed the bacilli.

The extreme whiteness of the curd in the defective cans suggested insufficient sterilizing heat as the cause of the defect. The fact that only a portion of the cans in the batch showed this defect appears further to indicate lack of uniformity of heat distribution in the sterilizer, as explained in Chapter XIV under "Distribution of Heat in the Sterilizer." The cases of bitter evaporated milk that have come to the attention of the author had to do with milk manufactured in late summer. In each case rather low-temperature sterilization was practiced, recurrence of the defect was prevented by raising the sterilizing temperature above 236° F. and improving the heat distribution in the sterilizer.

A case of bitter evaporated milk was studied by Hammer,[206] who isolated a small rod-shaped organism for which he proposed the name Bacillus amarus. Pure cultures inoculated into normal evaporated milk and incubated at 37° C. slightly increased the acidity, caused a distinct bitter flavor and upon prolonged incubation produced a firm coagulum. The extent of coagulation, however, was not uniform in all cases. Material from 6 to 21-day old cultures on whey agar gave growth when heated to 80° C. (176° F.) for ten minutes.

Spitzer and Epple[207] investigated a case of bitter evaporated milk, in which the troublesome organism appears to have been of a different type than was the case in the bitter evaporated milk epidemics under observation by Hunziker and Wright,[198] Hammer[206] and Hunziker and Cordes,[201] as described above. Spitzer and Epple found the bitterness to be due to the presence in the evaporated milk, of an organism that corresponds with Migula's (1900) classification of Bacillus panis as described by Lawrence and Laubach.[208]

This organism is a non-motile bacterium, rod-shaped, with rounded ends and measuring about .4 by 2.0 microns. It is spore-bearing, the spores forming readily in 48 to 72 hours and appearing usually near the center of the rod. The organism is capsulated and is very resistant to heat. Spitzer and Epple found it to survive a temperature of 250° F. for 8 minutes, but to be destroyed at the same temperature upon 10-minute exposure. The organism does not form gas, nor does it coagulate the casein. The contents of the can appear perfectly normal to the eye, the only change noticeable is the intensely bitter taste. It is an active proteolytic germ capable of secreting enzymes which are proteolytically active, rapidly breaking down the proteids of milk into large quantities of peptones and lower nitrogenous compounds of complex nature. The authors suggest that the excessive peptonizing function of this organism may be the primary cause of the bitterness.

The cultural characteristics and thermal death-point of this organism suggest that the presence of this germ in evaporated milk, and the spoilage of the product, are not due to a faulty process of sterilization, but are the result of conditions in the factory that permit this germ to lodge, breed and to contaminate the milk, such as insanitary condition of pipes, pumps, homogenizer, filling machines, etc.

FISHY FLAVOR IN EVAPORATED MILK

General Description.—This flavor defect is rare. Hammer[209] reported a case of fishiness in evaporated milk. The defect was found in a tin that had reached the consumer. The odor and flavor were distinctly fishy. The acidity was .56 per cent as compared with .32 per cent in a normal can from the same case. The fishy milk contained a few small lumps but its appearance was otherwise normal.

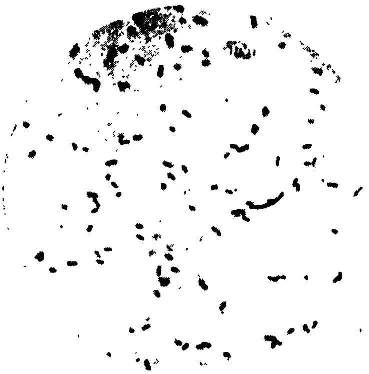


Fig. 118. Bac. ichthyosmius, causing fishy flavor in evaporated milk
Courtesy of B. W. Hammer

Cause and Prevention.—Sterile milk inoculated with material from the fishy tin developed a decidedly fishy odor upon incubation at room temperature for three days or more. Pure cultures of the organism inoculated into sound evaporated milk caused the same defect in a few days. There was a slight distention of the cans and upon opening a small amount of gas escaped. Small lumps of curd were present. The acidity increased from .32 per cent to .59 per cent, calculated as lactic acid. The fishiness was more pronounced when incubated at room temperature than at 37° C. The organism responsible for the fishiness was of rod shape, 1.0 to 2.1 microns long and .6 to .8 microns wide. No spores were observed. Cultures exposed to 70° C. (158° F.) for 5 to 10 minutes gave no growth. Its low resistance to heat suggests that this organism would not survive the sterilizing process and that the defect must have been due to contamination resulting from a defective can. Hammer found this organism to liquefy gelatin and to digest the casein. He believed it to be closely related to the Proteus group and proposed the name Bac. ichthyosmius.

GRAINY SEDIMENT IN EVAPORATED MILK

General Description.—There is a tendency in evaporated milk for a deposit to appear in the bottom of the tin upon aging. This deposit consists of a granular material of white color and gritty, insoluble non-crystalline character. The rapidity with which this sandy material collects and the amount of deposit that forms vary with the character of the milk, conditions of manufacture and temperature of storage.

Causes and Prevention.—The gritty, granular deposit in evaporated milk has been found to consist of salts of calcium and magnesium. Sato[210] reports that analysis of the sediment yielded tri-calcium phosphate $Ca_3(PO_4)_2$, magnesium phosphate $Mg_3(PO_4)_2$, and tri-calcium citrate $Ca_3(C_6H_5O_7)_2$. Mojonnier and Troy[42] also studied the granular deposit in evaporated milk and report it to be tri-calcium citrate.

Effect of Process of Sterilization.—The fundamental cause of the appearance of gritty sediment appears to be the effect of the sterilizing heat on the milk. As explained in Chapter XV on "Factors Influencing Heat Coagulation of Milk," the reaction of heat coagulation has to do with the precipitation of calcium and magnesium as phosphate and citrate. The calcium citrate precipitates from solutions upon boiling.

The relatively large amount of sediment usually found in evaporated milk sterilized at temperatures and time exposures sufficient to darken its color suggest that the tendency of sediment formation increases with an increase in temperature and time of sterilization.

While the heat reaction undoubtedly plays an important role in the formation of the deposit found in evaporated milk, it appears to be not the only factor involved, as suggested by Mojonnier and Troy[42] who demonstrated experimentally that sediment may form in evaporated milk condensed and sterilized in the absence of heat.

Effect of Composition of Milk and Concentration of Evaporated Milk.—Experience in commercial manufacture has shown that the tendency to form sediment and the amount of sediment deposited are usually greatest in evaporated milk of high concentration, a fact due probably to the greater concentration of mineral salts and to the more intense action of the sterilizing heat on milk with a higher concentration of milk solids, as explained in Chapter XV.

Differences in amount of sediment observed in milks of the same concentration and which have received the same treatment in manufacture, are presumably attributable to fluctuations in ash content and salt balance. As shown in Chapters XV and XXIII, the mineral elements of milk and their salts vary considerably with period of lactation and feed, the calcium and magnesium increasing as the period of lactation advances, while green feeds tend to augment the amount of citric acid and phosphorus present.

Effect of Temperature of Storage on Sediment in Evaporated Milk.—The temperature at which evaporated milk is held after manufacture is a controlling factor in the formation of sediment. The higher the storage temperature, the larger the deposit. Mojonnier and Troy[42] show that at 45° F. there was no sediment after four months storage. At 68° F. there was considerable sediment in 78 to 110 days, and at 85° F. one month storage yielded a large amount of sediment. When once formed, these crystals remain permanent; they fail to return to solution when the temperature of the milk is raised.

The marked increase in sediment with rising storage temperature appears to be attributable to the fact that calcium citrate, similarly as other lime salts, is most soluble at low temperatures and becomes more and more insoluble as the temperature rises. It is possible also that the diminished viscosity of the milk at the higher temperatures favors the formation and growth of these mineral crystals and facilitates their separation.

Fat Separation in Evaporated Milk.—Before the advent of the homogenizer fat separation in evaporated milk was a common defect. The intensity of fat separation was augmented in the case of milk in which fat globules of large size predominated, such as milk from the Channel Island breeds and milk produced during the early stages of the period of lactation. Unless the process of manufacture was so controlled as to secure maximum viscosity, the formation of a deep layer of cream in the tins was unavoidable and not infrequently this cream churned into lumps of butter during transportation.

The degree of viscosity necessary to prevent fat separation was accomplished by prolonging the process of sterilization, stopping the reel of the batch sterilizer at short intervals and permitting the formation of a soft jell. When skillfully operated, this procedure increased the viscosity sufficiently to successfully prevent fat separation. These precautions, however, augmented the danger of the appearance of a permanent heat curd in the case of milk with a naturally low heat coagulation point, and the prolonged heat exposure tended to darken the color, impairing the commercial value of the finished product.

The introduction of the homogenizer eliminated the troublesome defect of fat separation as a serious problem. Homogenization of the evaporated milk at a pressure of 3,000 pounds prevents fat separation. It permits the use of a sterilizing temperature high enough and a sterilizing time short enough to accomplish dependable germ destruction without objectionable discoloration and fat separation. For details see Chapter XIII on "Homogenizing."

BROWN DISCOLORATION OF EVAPORATED MILK

General Description.—The ideal color of evaporated milk is a rich creamy color, resembling the natural creamy tint of raw cream. Slight fluctuations in the shade of the color, such as occur between seasons and localities due to the effect of breed and feed have no effect on the commercial value of evaporated milk. Brown discoloration such as may result from heat treatment in manufacture, however, is a commercially objectionable defect. The usual causes of brown discoloration have to do with the process of sterilization, the addition of sodium bicarbonate, the temperature of storage. The reactions involved are discussed in detail in Chapter XXIII under "Color of Milk." The direct causes are briefly summarized in the following paragraphs.

Effect of Process of Sterilization and Forewarming.—The heat of sterilization tends to darken the evaporated milk. Prolonged exposure is more damaging to color than the use of high temperature. A short process in which the milk is rapidly heated to a high temperature and held there for a brief period usually does not alter the color noticeably. The effect is negligible. A prolonged process in which the temperature is raised slowly greatly augments the tendency for the milk to become objectionably brown, even in the presence of a lower maximum temperature. In order to preserve the natural color and to guard against brown discoloration, short-duration high-temperature sterilization is preferable to an extended process of low-temperature sterilization. The relation of temperature to time of sterilization, as given in Chapter XIV, provides a process that combines preservation of satisfactory color with dependable efficiency of sterilization and avoidance of spoilage.

The forewarming temperature has no appreciable effect on the color of the evaporated milk, unless the duration of forewarming is unduly long. When forewarming at near the boiling point for 30 minutes or longer there is a tendency for the color of the finished product to become noticeably darker.

Effect of Sodium Bicarbonate on Color of Evaporated Milk.—The use of bicarbonate of soda as a stabilizer or neutralizer tends to darken the color of evaporated milk; the brown discoloration becomes more pronounced, the larger the amount of bicarbonate added. The color-darkening effect of sodium bicarbonate can be prevented by neutralizing the soda with an acid, such as lactic acid, to a point where its addition will not change the acidity (pH) of the milk. The use of other stabilizers, such as di-sodium phosphate, or sodium citrate, has no color-darkening effect.

Effect of Storage Temperature on Color.—The temperature of storage has a marked effect on the color of evaporated milk. The higher the temperature the more rapid and intense is the brown discoloration. At a storage temperature of 45° F. or below no color change occurs. At room temperature progressive darkening is quite noticeable, at higher temperatures the brown discoloration proceeds rapidly and the milk becomes very dark in color. For maintenance of a satisfactory color and the prevention of age-darkening, therefore, evaporated milk should be stored at temperatures considerably below room temperature, preferably between 35 and 45° F.

PART VI

Manufacture of Milk Powder

CHAPTER XXVII

DEFINITION, DEVELOPMENT, ANNUAL PRODUCTION AND SYSTEMS OF MILK DRYING

DEFINITION

Milk powder, dried milk, dehydrated milk, desiccated milk, pulverized milk, milk flour, milk flakes, is made from cow's whole milk, or partly or wholly skimmed milk, or from milk that has been enriched by additional milk fat, to which sugar or alkalies or salts, may or may not have been added, and which has been evaporated to relative dryness, either under atmospheric pressure or in vacuo.

Most of the milk powders made during the early days of the industry contained added cane sugar and casein stabilizers in the form of alkalies or mineral salts. The purpose of the addition of casein stabilizers was to preserve the solubility of the finished product. Sugar is added to granulate the dough and facilitate the removal of moisture during the later stages of the drying process. Since those days the processes of manufacture have undergone vast improvement, so that a high degree of solubility and low moisture content can now be attained without the addition of protein stabilizers and sugar.

HISTORY AND DEVELOPMENT OF INDUSTRY

The origin and history of the milk powder industry are very closely related and intimately connected with those of the condensed milk industry. The fundamental purpose of the two products is one and the same, i. e., to preserve milk as nearly as possible in its natural condition, and to reduce its bulk to the minimum, so as to make possible its economical transportation to all parts of the world. The difference between milk powder and condensed milk is mainly one of degree of concentration.

It is not surprising, therefore, that the inventions of processes of manufacture of the two products date back to about the same period, the middle of last century, and in most cases the inventors of the one product had also in mind and gave due consideration to the possibilities of the other. But unlike the condensed milk industry, with its simpler and more rapidly developed process, with its product readily accepted by the trade, and the development of which received a tremendous impetus in its early days by the food shortage during the Civil War, the milk drying industry developed more gradually. The invention and perfection of processes whereby a marketable product could be manufactured required more time, and the demand for a milk product, in dry form, failed to be sufficiently great to encourage and stimulate the investment of capital.

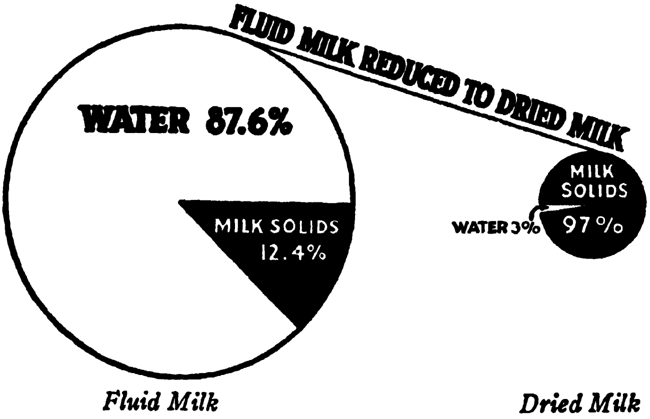


Fig. 119

To Marco Polo is attributed the description of a dried milk of the Mongols of the thirteenth century. Next we hear of dried milk in tablet form developed in 1810 by Nicholas Appert, the inventor of canning. The first commercially usable process of making dried milk was invented by Grimwade, to whom was issued a patent by the British government in 1855. However, the perfection of processes for the commercial manufacture of dried milk is of comparatively recent origin, dating back to the closing years of the nineteenth century and to the first decade of the twentieth century.

In the United States the first successful dried milk manufactured was malted milk, the process being invented in 1883 and the product first put on the market in 1887. While malted milk is a combination of whole milk and extract of malted barley and wheat flour reduced to dryness, and, therefore, is not a dried milk in the sense of milk powder as manufactured and known today, its advent constituted an important step in the development of the milk drying industry.

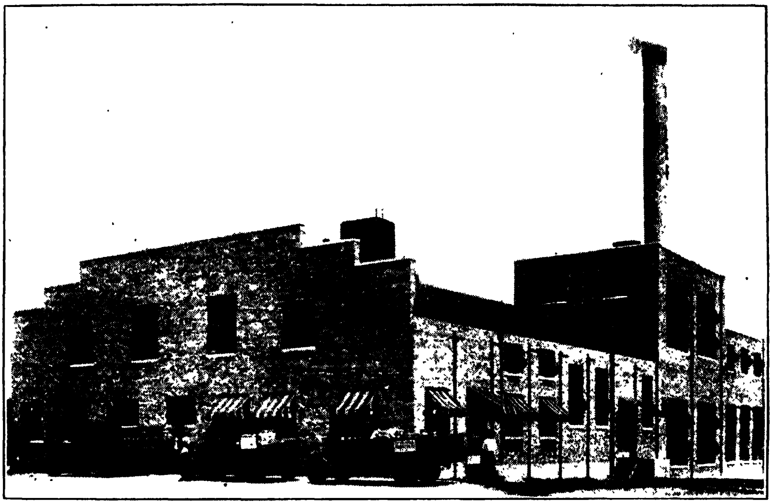


Fig. 120. Milk drying factory, Tyler, Texas
Courtesy of Douthitt Corporation

ANNUAL PRODUCTION OF MILK POWDER IN UNITED STATES

It was not until 1898 that milk powder without the admixture of ingredients foreign to milk was manufactured in this country. From that time on, however, the milk drying industry made rapid progress. Both American and foreign inventions and their perfections materialized in rapid succession. The quality of the product was materially improved and has today reached a high degree of perfection and the annual output has grown to large dimensions, especially that of powdered skimmilk, though considerable quantities of powdered whole milk and powdered cream are also manufactured, as shown in Table 42.

Table 42.—Annual Production in U. S. of Dried Milk Products*

Year	Dried Whole Milk	Dried Skimmilk	Dried Cream	Dried Buttermilk	Malted Milk
	Pounds	Pounds	Pounds	Pounds	Pounds
1916	2,123,251	16,463,362		342,485	11,654,000
1917	3,138,809	22,624,357		2,557,228	13,852,000
1918	4,164,334	25,432,007	654,360	4,341,157	15,623,000
1919	8,660,785	33,076,131	592,070	5,278,827	17,436,000
1920	10,334,000	41,893,000	309,000	5,585,906	19,725,000
1921	4,242,471	38,545,718	129,706	7,708,384	15,651,000
1922	5,599,000	41,217,000	118,000	9,007,000	13,659,000
1923	6,569,000	62,251,000	328,000	13,032,000	15,331,000
1924	7,887,000	69,219,000	330,000	18,058,000	15,899,000
1925	8,931,000	73,300,000	339,000	22,772,000	18,050,000
1926	10,768,000	91,718,000	331,000	31,378,000	20,673,000
1927	11,464,000	118,123,000	338,000	38,435,000	22,116,000
1928	9,605,000	147,990,000	673,000	45,502,000	21,128,000
1929	13,202,000	207,579,000	294,000	54,215,000	22,850,000
1930	15,440,000	260,675,000	400,000	64,601,000	22,691,000
1931	12,627,000	261,938,000	161,000	50,535,000	19,197,000
1932	11,983,000	270,194,000	80,000	48,712,000	13,215,000

*American Dry Milk Institute, 1934.

Table 42a.—Annual Production of Dried Milk in Different Countries*

Countries	1928	1929	1930	1931
Australia[1]	53,949,000	51,582,000	45,665,000	41,410,000
Canada[2]	14,823,677	14,955,151	16,661,278	15,391,049
Denmark[3]	1,102,000			1,455,000
Great Britain[4]			15,008,000	
Italy[5]				1,764,000
Japan[6]	1,357,000	1,204,000	1,708,000	1,614,000
Netherlands[7]			10,685,000a	31,164,000b
New Zealand[8]	17,219,000	13,736,000	15,200,000	12,845,000
Switzerland[9]	99,207,000	97,443,000	95,900,000	88,184,000
United States[10]	158,268,000	221,075,000	276,515,000	274,726,000

*Statistics furnished by U. S. Dept. of Agr. Bureau of Agr. Economics.

[1] Includes condensed and concentrated milk.

[2, 3, 4, 5, 6, 7, 8] Include powdered whole milk and powdered skimmilk.

[9] Includes condensed milk used for chocolate.

[10] Includes powdered whole milk, skimmilk and cream.

[a] For 1922.

[b] For 1932.

PRINCIPLES, SYSTEMS AND PROCESSES EMPLOYED IN THE DRYING OF MILK

The drying of milk may be accomplished by the application of cold or heat. While the utilization of cold for drying milk has not reached the commercial stage, numerous systems and processes have been developed for the successful manufacture of dried milk by the use of heat. The several principles, systems and processes are conveniently grouped in the following schematic classification.

Schematic Classification of Systems and Processes of Milk Drying

Drying by use of
- Cold—Freezing out the water.
- Heat
  - Dough-drying system
    - Using vacuum pan with mechanical agitator.
    - Blowing heated air through heated milk, condensing to a dough, then finishing in shelf driers or on belts running through heated tunnel.
  - Film-(drum) drying system
    - Atmospheric drums.
      - Heating surface above boiling point.
        - Using fluid milk.
        - Using pre-condensed milk.
      - Heating surface below boiling point.
    - Drums incased in vacuum chamber.
  - Spray-drying system
    - Pressure spray.
      - Spraying fluid milk.
      - Spraying pre-condensed milk.
    - Centrifugal spray.

Drying Milk by Application of Cold.—This system is based on the principle of "freezing out" the water of milk. It is a well-known phenomenon that when milk freezes there is a tendency for the water to separate from the milk solids. The completeness of the separation of the water from the dry matter of milk is accelerated by proper agitation during the freezing action. The procedure of the refrigeration system of drying milk is briefly as follows:

The milk is cooled gradually and under constant agitation to below the freezing point of water. The agitation at the point of freezing must be of such character as to cause the formation of a fine snowlike mass of crystals. The fine crystals thus obtained consist almost exclusively of frozen water, and surrounding them are the milk solids in unfrozen condition. The entire mass is then centrifuged at high speed whereby the milk solids are separated out and discharged in the form of a thick paste, while the crystals of frozen water remain in the separator bowl. The paste of milk solids is then evaporated to dryness in a heated drying chamber at moderate heat. A process of this nature was developed and patented in Germany by Byron F. McIntyre, East Orange, New Jersey, U. S. A.

The process of drying milk by refrigeration has, so far as available data indicate, never passed the laboratory state of development and has not found application in the commercial drying of milk. It would appear that one of the most serious difficulties encountered in the commercial utilization of this process would lie in the incomplete recovery of the milk solids.

Drying Milk by Application of Heat.—Without exception, all the processes that have found commercial application in the manufacture of milk powder are based on the principle of removing the water by evaporation in the presence of heat. The processes of desiccating milk, which have proven commercially successful and have found wide application, may be conveniently grouped into three fundamental classes, according to the predominating principle upon which they are based. These are:

1. Dough-drying system.
2. Film-drying system.
3. Spray-drying system.

For detailed discussion of the more outstanding principles covered in some of the patents of these processes the reader is referred to the following brief descriptions and illustrations.

CHAPTER XXVIII

THE DOUGH-DRYING AND FILM-DRYING SYSTEMS

THE DOUGH-DRYING SYSTEM

To this group largely belong the earlier and cruder processes. The milk is condensed in any manner, either by heating in open pans under atmospheric pressure and usually with the help of mechanical agitation; or in the vacuum pan with or without mechanical agitation; or in open vats by blowing heated air through the milk, to a high degree of concentration and to a dough-like consistency. The concentrated product is then spread on trays or other similar containers, and dried in vacuum chambers or in other vaults or drying apparatus, provided with heating devices or currents of hot air. The dried product is subsequently ground to a fine powder. Examples of this type of milk-drying processes are the Grimwade process, the Wimmer process, the Campbell process and others.

The Grimwade Process.—This process, invented by Grimwade and patented in England in 1855, consisted briefly of adding an alkali (sodium or potassium carbonate) to the fresh milk, then evaporating in open jacketed pans and with constant agitation, to a dough-like consistency. Sucrose was then added. The mixture was pressed into ribbons by passing between rollers, further dried and pulverized. The alkali served to render the casein more soluble. The purpose of the admixture of sugar was to produce granulation of the dough, facilitating the removal of moisture during the later stages of the drying process. Evaporation in open pans was later superseded by the use of the vacuum pan. The Grimwade process was in commercial use for several years.

The Wimmer Process.—The milk is boiled in a vacuum pan similar to that used in the manufacture of condensed milk. The vacuum pan has a deep steam jacket for heating, but in the place of the usual coils, the pan is equipped with a mechanical stirrer. The milk is condensed at a relatively low temperature and the stirrer revolves until the water content of the milk is reduced to about 30 per cent and the milk has become porous and crumbly, though it still forms a compact mass. The drying is then completed in the open air and without additional heating. The product is then ground to a powder. This is the process invented by Ole Bull Wimmer of Copenhagen, Denmark and patented in 1901.

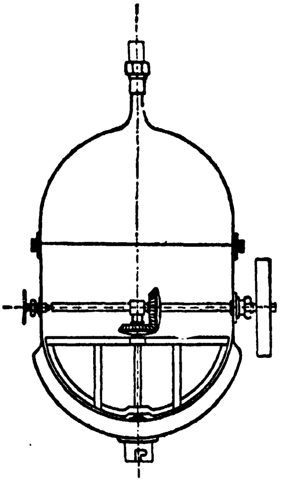


Fig. 121. The Wimmer milk dryer

The Campbell Process.—This process was invented, patented and improved by J. H. Campbell of New York City, U. S.

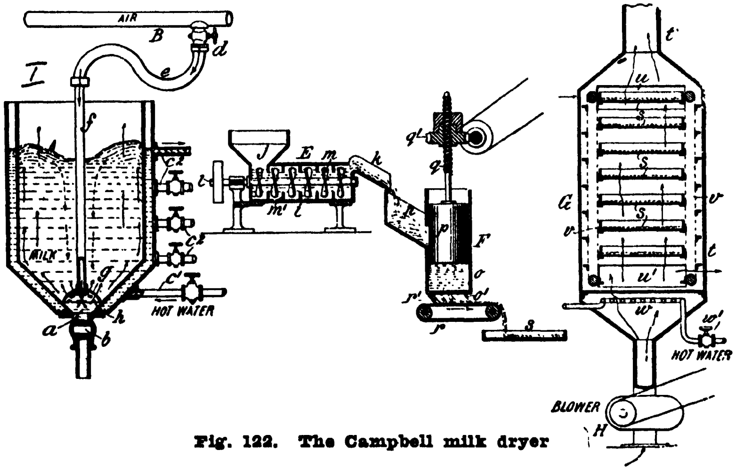


Fig. 122. The Campbell milk dryer

patent Nos. 668,159 and 668,161, February 19, 1901; U. S. patent No. 718,191, January 3, 1903; U. S. patent No. 762,277, June 4, 1904; and by J. H. and H. C. Campbell, U. S. patent No. 668,162, February 19, 1901; and by C. H. and P. T. Campbell, U. S. patent No. 771,609, October 4, 1904.

The Campbell process consists essentially of concentrating milk to a high degree of concentration by blowing heated air through it in an open vat. The milk is reduced to a very thick consistency, resembling a batter. The concentrated milk is then removed from the evaporating tank, is reduced mechanically to small units by means of a pugging or shredding machine, or otherwise. This subdivided product is then placed on shelves or trays and dried in a chamber heated to a temperature below the coagulating point of the albumin. Or the drying is finished by passing the partly desiccated milk on a carrier belt through a steam-heated drying tunnel.

THE FILM-DRYING SYSTEM

General Description.—The film-drying, or drum-drying system consists of applying the milk in a thin film upon the surface of a steam-heated, revolving, metal drum and removing the dried film from the drum surface by means of a stationary scraper. The dried milk film so removed, which has the character of a thin, shredlike sheet, drops into a trough or hopper, from which it is usually continuously removed by a spiral conveyor to the grinder and bolter where it is reduced to a powder of the desired fineness of grain.

The principle of drying liquids on a heated, revolving, metal drum did not originate with the milk-drying industry. As far back as the middle of the nineteenth century, liquid gelatin was desiccated into dry gelatin sheets by a similar process. The application of drum-drying to milk and milk products, however, is a more recent event, dating back to the last decade of the nineteenth century. From the standpoint of its compactness, economy of space, and simplicity and economy of operation, the drum dryer, with its ever-ready drying surface, has distinct advantages as a milk dryer.

Drum Dryers and Their Operation.—The drum dryers used in commercial manufacture of dried milk are either single drum or double drum units, operating under atmospheric pressure or inclosed in a vacuum chamber. The drums are constructed of a close-grain cast iron. They are heated with steam under pressure. The drums are equipped with suitable arrangements for steam intake and condensate outlet. An air vent provides removal of entrained air. The drum is rotated by a worm gear. In double-drum units the drums revolve in opposite directions, turning downward toward each other. Each drum is equipped with a stationary scraper, knife, or "doctor" for removing the film of dried milk. Above the drums extends a sheet metal hood which collects and carries off the vapors that escape from the drying milk. The hood generally exhausts into the outside atmosphere. The removal of the vapors is facilitated by forced ventilation provided by a suction fan.

For uniformity of drying, the boiler pressure should be carried at least 20 pounds, or preferably more, above the steam pressure in the drying drums, and the steam line should be equipped with suitable pressure-reducing valve, safety vent and temperature control. When starting operation and before "turning on" the milk supply the drums are set in motion and steam is turned in until the drums have attained the desired drying temperature. They are then ready for the milk film. Upon completion of the day's operation the drum surface and scraper should be thoroughly washed, removing all remnants of milk, and then rubbed dry.

Feeding the Milk Upon the Drying Drum.—The manner of feeding the milk to the drum surface varies with the type of drum dryer. In the Just-Hatmaker type of dryer, which is a two-drum unit, the drums are close enough together (clearance approximately .02 inch) to form a trough for the milk supply on top between the drums. The milk level, or the depth at which the milk is carried in this trough, has a marked influence on the capacity of the drums; the higher the level the greater the volume of dried milk per hour.

In the case of single drum units, the drying drum itself may dip into the milk contained in a reservoir which extends over the entire length on the under side of the drum, the milk being carried at a level sufficiently high to cause the drum at its lowest side to dip into the milk; or the milk film may be applied to the drying drum by contact of the latter with a small auxiliary drum which revolves in the milk; or by spraying the milk upon the drying drum.

Uniformity of Film Thickness.—The maintenance of a film of uniform thickness largely determines the per cent moisture and the uniformity of dryness of the resulting powder, and it may affect also the solubility, flavor and color of the product. Its accomplishment constitutes an important problem. Efforts to provide a milk film of uniform thickness have brought forth numerous attempts and methods of applying the milk to the revolving drum, as shown in previous paragraphs.

None of the previously discussed means of applying the milk to the heating surface has proven ideal. In the case of the double drum unit of the Just-Hatmaker type, where the milk rests on top between the two drums, the uniformity of the film requires both drums to wear even throughout and to run true. Likewise, the direct and prolonged contact of the fluid milk, when not yet in the film form that dries rapidly, is considered harmful to the solubility of the dried milk. These objections have been minimized somewhat by modifications and improvements of the feeding arrangement.

In the case of most of the single drum units, where the milk is usually applied to the drying surface either by dipping or by surface contact with an auxiliary roll that revolves in the milk, it is necessary to pre-condense the milk in order to insure a film of satisfactory thickness on the drying drum.

Some very ingenious designs of spraying the milk upon the drying drum have been devised, such as impinging the condensed milk spray from the tubes of the rapid-circulation evaporator against the drying drum, or spraying the milk on the drum by means of a threaded, rapidly revolving, projecting roll. Unfortunately, none of these later attempts at spraying has proven entirely satisfactory. Their outstanding faults lie in their inability to produce a milk film of sufficiently uniform thickness to insure freedom from variations in moisture content of the finished product and from the danger of jeopardizing the flavor, color and solubility of the dried milk.

Steam Pressure and Speed of Drying Drum.—In drum drying, the drying period is limited to the journey of the milk film on the revolving drum between milk feed and scraper. This usually represents about three quarters of one complete revolution of the heated drum. The steam pressure in the drying drum is the controlling factor that predominatingly determines the rapidity of evaporation. The drying of the milk film must be completed by the time the film approaches the scraper. The accomplishment of this requires a certain definite relation of drum speed to steam pressure for a given size of drum.

In the commercial operation of the double drum unit of the Just-Hatmaker type, which is the most widely used atmospheric drum dryer, the steam pressure varies within wide limits, ranging from below 40 pounds of steam (286°F.) to as high as 100 pounds of steam (337.9°F.). According to Scott,[211] Reavell mentions a speed of 12 R. P. M. for 40 pounds steam pressure and a speed of 20 R. P. M. for 100 pounds of steam pressure. The drum size is not given. Comb and Hubbard[212] used the Buflovac atmospheric double drum dryer with a drum size of 24" x 36". They found a drum speed of 24 R. P. M. for a steam pressure of 50 to 60 pounds and a drum speed of 36 R. P. M. for a steam pressure of 85 pounds satisfactory combinations.

Factors Affecting Capacity of Drum Dryer.—An increase in steam pressure that permits of a greater drum speed consistent with satisfactory completeness of drying, obviously increases the capacity of the dryer. Other factors affecting the capacity of the dryer are temperature of fluid milk, level or depth of milk trough and concentration of the fluid milk. Comb and Hubbard report the following results relative to effect of steam pressure, drum speed and temperature of milk on capacity of dryer:

Table 43.—Effect of Steam Pressure, Drum Speed and Temperature of Milk on Capacity of Dryer

Temperature of Milk Degrees F.	Steam Pressure Pounds	Drum Speed R. P. M.	Dried Milk per Hour Pounds
50 to 60	60	24	53.0
50 to 60	85	36	64.0
155	60	24	58.0
155	85	36	72.5
185	60	24	69.0
185	85	36	85.0

Table 43 shows that the preheating of the fluid milk to 185°F. increased the capacity of the dryer approximately 31 per cent over that of using unheated milk at 50 to 60°F. The figures further show that, regardless of drying pre-heated or raw milk, an increase of the steam pressure from 60 to 85 pounds and of the drum speed from 24 to 36 R. P. M. increased the capacity of the dryer approximately 23 per cent. The same authors show experimentally that a trough with an abnormally low milk level reduced the capacity of the dryer approximately 23 per cent below that of the normal level, while a high milk level (ready to overflow) increased the capacity about 30 per cent above that of the normal level.

Film-Drying of Fluid or Pre-Condensed Milk.—It has been shown in previous paragraphs that pre-condensing is practically indispensable in the case of single drum dryers, where the transfer of the milk to the drying drum resolves itself into either direct dipping in the milk or contact with an auxiliary drum that revolves in the milk. In either system, the fluid milk, because of its low viscosity, is incapable of providing a satisfactory film thickness.

When using the double-drum dryer, with the trough of milk resting on top between the drums, pre-condensing is neither necessary nor desirable. The milk constituting this trough is in direct contact with the hot drum surface. It boils and is subject to some evaporation. It supplies the drum surface with a film of sufficient thickness. If it were pre-condensed the quality of the resulting powder would be jeopardized because the higher concentration renders its unstable constituents more sensitive to the damaging action of high temperature.

Temperature and Time of Film-Drying.—The heat-unstable milk constituents are most subject to heat damage in the presence of moisture. Definite information regarding the optimum temperature-time relationship for maximum preservation of the physical properties of the dried milk is meager. Available data suggest that it is the time of heat exposure and the concentration more than the exact temperature used that are the determining factors. Reavell[213] found that, for a given drum size, the moisture content of the powder decreases with increased steam pressure, and increases with higher drum speed.

He further reports that there appears to be a certain drum speed above which the moisture content increases rapidly.

Since an increase in steam pressure hastens the drying, it makes possible the use of more rapid drum speed and thereby shortens the time of heat exposure. Comb and Hubbard's results show that the higher steam pressure (85 pounds, 316.3°F.) accompanied by the increased drum speed (36 R. P. M.) did not change the percentage of protein insolubility nor the moisture content. The results of Wright[214] show that it is that phase of the milk film on the drying drum that has become highly concentrated and before it reaches the dry stage, that suffers the greatest increase of insolubility for a given time-temperature factor. See also "Solubility of Film-Dried Powder" in Chapter XXXI.

Removal of Dried Milk from Drums.—Knoch[215] emphasizes the importance of proper removal of the dried film from the drum and the quality-damaging effect of incomplete removal. The usual arrangement for freeing the drum from the film of dried milk consists of an adjustable knife, scraper, or "doctor," that extends over the entire length of the drum. The position of the scraper is at a point that permits the revolving drum to turn, as much as possible, one complete revolution after receiving a film of fluid milk.

The scraper presses against the drum by means of weights attached to suitable levers, or by springs or by jackscrews. Proper scraping requires a fine adjustment of the knife edge to the surface of the drum. Reavell[213] points out the difficulty of complete removal of all the dried milk at each revolution with a single knife. There is a tendency toward warping of the knife, due to the fact that the cutting edge, which is in direct contact with the hot drum surface, is heated to a higher temperature than other parts of the scraper. This causes uneven expansion and the resulting distortion tends to permit portions of the film to remain on the drum for more than one revolution. This prolonged heat exposure damages the quality of that portion of the product and may cause discoloration, insolubility and spoilage.

Knoch showed that the dried milk scraped off during the first revolution of the drum is invariably of superior quality, and that the solubility of the powdered milk diminishes with the increasing number of revolutions. Scott[211] points out that the completeness of removal of the milk film is materially improved in the case of the Kestner drum dryer in which the long one-piece knife is substituted with a series of independent short knives which are arranged in staggered positions, thus effectively covering the whole drum surface.

Aside from the mechanics of the "doctor," proper removal of the dried milk film requires uniformity of drum material throughout, that will prevent uneven wear of the drum surface, and suitable temper of the knife that will withstand abrasion of the dried film consistent with minimum wear of the drum. Attempts to improve the adjustment of the knife in a manner to bring about maximum closeness of scraping have been accompanied by the increased tendency of removing particles of metal from the drum surface resulting in excessive metallic contamination of the dried milk with inevitable damage to its keeping quality. See also Chapter II on "Metals in Dairy Equipment."

These observations emphasize the importance of satisfactory means for the efficient removal of the film of dried milk from the drum. They show the weaknesses of the available devices in use and the need of further improvement of this phase of the equipment for and operation of drum drying.

Film-Drying Under Atmospheric Pressure or in Vacuum.—It has been explained in previous paragraphs that high temperature and prolonged exposure of the milk solids to the drying heat is detrimental to the solubility of the finished product. Long experience in milk condensing has likewise demonstrated the undisputed merits of evaporation at temperatures below the boiling point of water, such as is made possible by condensing in vacuo. These facts have furnished the background for the development of equipment and methods of drum-drying under reduced pressure, encasing the drying drum or drums in an airtight chamber on which a vacuum is maintained during the operation of dehydration.

Advantages of Vacuum Drum Dryers.—Milk powder manufactured by the use of the vacuum drum dryer possesses a high degree of solubility and its quality is superior to that of the atmospheric drum dryer. In the vacuum drum dryer the greater difference between the temperature of the milk and that of the heating medium provides more rapid transmission of heat, and this in turn increases the rapidity of evaporation and drying, and the drying operation in vacuo proceeds at a lower temperature. Additional protection of the milk against contact with high temperature heating surfaces is provided in the operation of some of the vacuum drum dryers by maintaining a partial vacuum also in the steam-heated drum.

Both the increased rapidity of drying and the lower temperature to which the milk is exposed make for preservation of the desired solubility. The near-sterile and inert atmosphere of the vacuum drying chamber protects the milk against contaminating and oxidative agencies, which in turn tends to improve the keeping quality of the milk powder.

Other advantages of vacuum drum dryers are the compactness of the drying unit as compared with spray-drying units, the comparatively close control of temperature conditions of drying and the feasibility of using exhaust steam, which makes for maximum economy of fuel.

Disadvantages of Vacuum Drum Dryers.—The chief disadvantages of the vacuum drum dryer are:

1. Relatively high initial cost of the necessary equipment, the cost being four to five times that of the atmospheric drum dryer.

2. The operating cost of the vacuum drum dryer is slightly higher as shown by Scott, who suggests further that pre-condensing should be carried as far as possible, preferably to concentrations of 40% milk solids, as the initial and operating costs for a vacuum pan are less than those for a vacuum film dryer of the same evaporative capacity.

3. As compared with the atmospheric drum dryer, inspection of the product during drying is more difficult. In the case of the vacuum drum dryer the spy glasses provide the only opportunity to watch the process, and defects are not rectified so readily. Being inclosed, there is also somewhat less ready accessibility for cleaning. This, however, may be corrected by the installation of proper manhole facilities.

The above considerations suggest that the use of the vacuum drum dryer would be of no particular advantage in the case of liquid milk products which are not in complete solution in the original liquid state or the dried product of which is intended for stock feed or other purposes that do not require high solubility or superior quality, as is the case with dried butter milk, some of the dried skimmilk and similar by-products.

On the other hand, the vacuum drum dryer is admirably suited to the dehydration of milk and milk products intended for human consumption and where ready solubility and high quality of the finished product are of prime importance, as is the case with much of the dried skimmilk, dried whole milk, dried cream and malted milk.

Homogenizing Milk for Drum-Drying.—The film-drying action does not homogenize the milk. In the case of skimmilk, homogenization is obviously not needed. In the case of whole milk powder and cream powder, however, homogenization is necessary in order to prevent objectionable churning when reconstituting the powder. Homogenizing at 2,500 to 3,000 pounds of pressure at approximately 140°F. is sufficient to prevent the churning tendency.

Film-Drying Inventions and Processes.—Some of the United States and foreign patents of equipment and processes of the film-drying system, that have found wide commercial application are briefly described in succeeding paragraphs.

ATMOSPHERIC DRUM DRYERS

The Knoch Process.—Dr. C. Knoch[215] invented and received a German patent in 1894, on an apparatus which made possible the drying of milk on a drum at a temperature of 60°C. (140°F.). Skimmilk powder so produced was readily soluble. Experiments with whole milk, however, failed to yield a product of the desired keeping quality. It is probable that the low temperature used was insufficient to destroy lipolytic enzymes which caused hydrolysis of the fatty acids and rancidity.

The Just Process.—This process appears to be the first of its type that found wide commercial application in the desiccating of milk. It was invented and patented by John A. Just of Syracuse, New York, U. S. patent No. 712,545, November 4, 1902.

The essential equipment involved in the Just process consists of two horizontal steam-heated revolving metal cylinders, these cylinders are installed sufficiently close to each other so that there is contact at their periphery; a milk distributing tank (7) with adjustable discharge (8 and 9) in the center over and between the two cylinders; scrapers or knives (11) which remove the dried film of milk from the cylinders; and receptacles (12) which receive the finished powder.

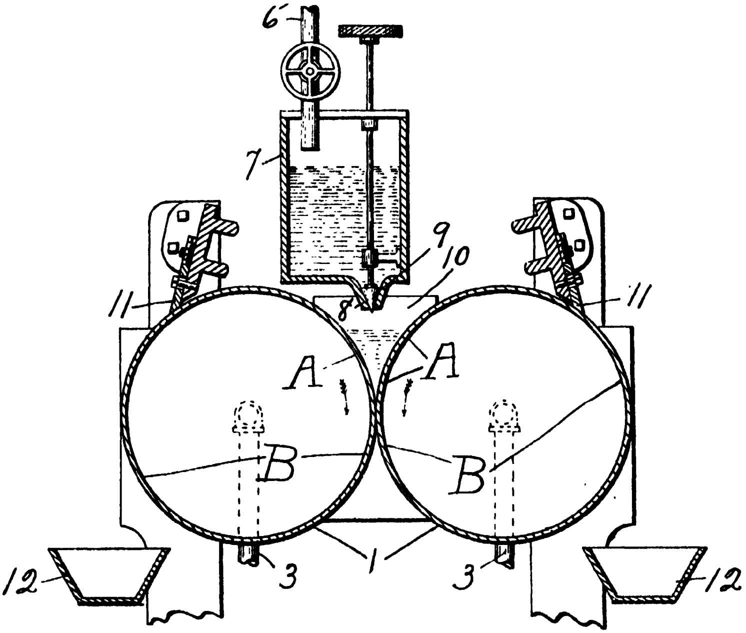


Fig. 123. The Just drum dryer

The patent claims of the Just process cover the treatment of the milk with calcic chloride ($CaO + CaCl_2$), or with the double salt of sodium and calcium citrate, to reduce the acidity of the milk, and with alkaline hypochlorite for the purpose of preserving the fatty acids in the finished product, the heating and boiling of the milk by bringing it in contact with a heating surface of a temperature above 212°F. and below 270°F., allowing the thus treated and heated milk to flow in regulated quantities on the surface of the steam-heated revolving metal cylinders, where it is dried in the form of a film and from which it is removed by mechanical scrapers. The high temperature to which the milk is heated obviously reduces the solubility of the finished powder. The purpose of neutralizing the acidity of the milk and the use of protein-stabilizers in the form of citrates before drying, is to minimize the solubility-destroying action of the high heat.

The Hatmaker-Process.—This is similar to the Just process. James R. Hatmaker of London, England, purchased the Just process for operation in Europe and later secured a patent of his own, which represents a modification of the original Just process, and which is known as the Just-Hatmaker process.

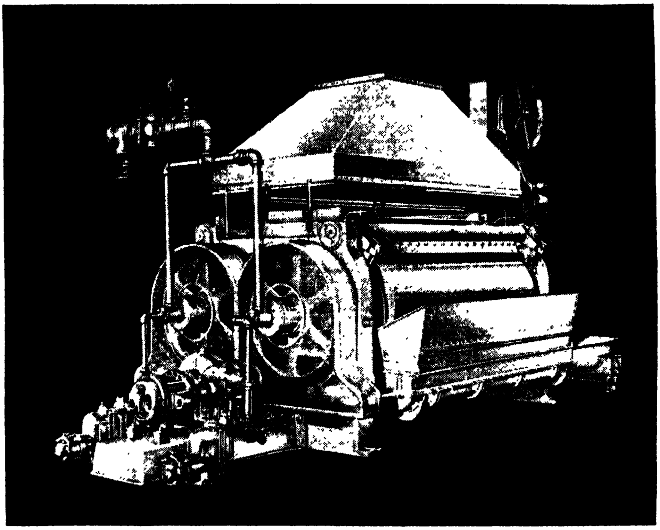


Fig. 124. The Just-Hatmaker type of drum dryer
Courtesy of Buffalo Foundry & Machine Co.

The Gathmann Process.—This process and equipment was invented and patented by Louis Gathmann of Washington, D. C., U. S. patent No. 834,516, October 30, 1906.

In this process, as in the Just process, the milk is dried in the form of a film on a revolving, steam-heated drum under atmospheric pressure. In this case, however, only one drum is used, the drum (A) is cone-shaped instead of cylindrical, its surface is spirally grooved or corrugated (a) and the adjacent surface against which the cone revolves is also similarly corrugated, the spiral grooves (b^1) running in the opposite direction from those on the cone, as is common in grinding-mills. Hence when the cone revolves the drying milk is kneaded and ground between the two surfaces and is gradually carried or pushed by the corrugated surface of the revolving cone to the smaller or discharge end of the machine.

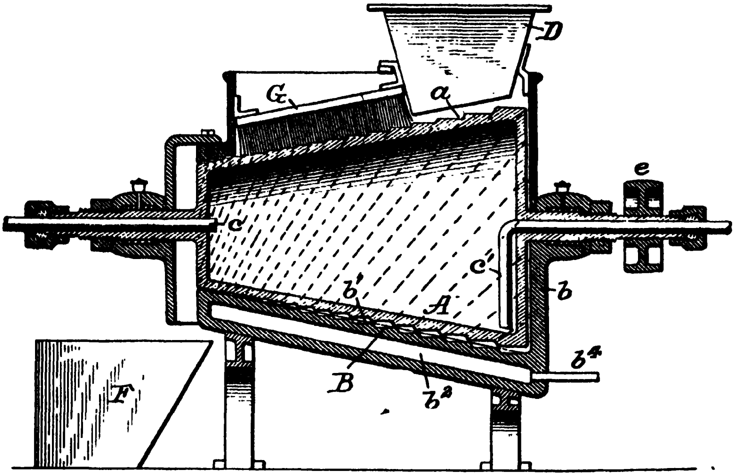


Fig. 125. The Gathmann drum dryer

A hopper (D) regulates and feeds the flow of the milk to the cone at its larger end and a brush (G), located near the smaller end of the cone, removes such parts of the dried milk as may adhere to the grinding surface. Baffle boards or dash boards are provided to receive any milk that may splash from the cone.

The patent claim covers the drying of the milk by feeding it to a continuously moving, heated surface, where it is permitted to form a comparatively thin layer, heating it to evaporate the water, and simultaneously subjecting it to a kneading, which gradually changes to a grinding action, as the milk solidifies, and forms a powder. The temperature of the heating surface is recommended to be that of boiling water, but may be between 212°F. and 270°F. The milk enters the hopper without pre-heating and without other treatment.

The Mignot-Plumey Milk Dryer.—This dryer was invented by Mignot and Plumey and is in commercial use in some of the milk powder plants in France. It consists of two revolving drums, one 30 cm. (12 inches) in diameter and the other 75 cm. (30 inches) in diameter. The smaller drum is not heated, it revolves in the milk contained in a reservoir and conveys a film of milk to the surface of the larger drum which is the steam heated drying drum. The thickness of the film of milk that is picked up by the large drum is controlled by the relative closeness of contact of the surfaces of the two drums. The temperature of the heating drum is maintained at 92 to 94°C. (197.6 to 201.2°F.). If the temperature rises higher than the above, the large cylinder presses closer against the small cylinder due to increased heat expansion; this causes the film of milk to be thinner and vice versa.

Because of the relatively low temperature at which the drum in this machine is operated, the drying proceeds more slowly than on steam-heated drums. Consequently the drum must revolve at lower speed. Also the operation of this dryer requires the pre-condensing of the milk in order to enable the small cylinder to transfer to the surface of the drying drum a milk film of adequate thickness. The chief advantage of this drum dryer and process lies in minimizing the solubility-destroying influence of the heat employed. The same principle applies also to the machine and processes of Gabler-Saliter and of Kunick.

The James Bell Milk Dryer With New Compressor Attachment.—This dryer was invented and is manufactured by James Bell Machinery, Pty., Ltd., Melbourne, Australia, and is in extensive use in Australia for drying whole milk, skimmilk and buttermilk.

Similarly as in the case of the Just-Hatmaker machine, the Bell unit consists of two steam-heated, revolving metal drums with stationary, adjustable knives or scrapers, which automatically remove the film of dried milk after each revolution of the drums.

One of the special features of the James Bell unit consists of the "New Compressor Attachment" shown at the front end of the drum frame. It comprises a gear-driven pump unit that makes possible the continuous return of the steam under pressure from the drums back to the boilers. This attachment takes the place of the steam traps ordinarily used. Its advantage lies in that it acts continuously, whereas the steam traps only operate intermittently. The compressor attachment, because of its continuous action and its ability to remove the steam under pressure, insures greater uniformity of drum temperature. This in turn makes for more uniform composition of the finished product. It is further claimed that this attachment materially increases the capacity of the machine and effects a considerable saving in fuel.

VACUUM DRUM DRYERS

The Passburg Process.—This process was invented and patented by Emil Passburg of Berlin, Germany, U. S. patent No. 726,742, April 28, 1903. This film dryer operates under reduced pressure. It consists of an outer casing in which revolves one steam heated, metal drum, an automatic milk supply regulating feed which keeps the milk in the vacuum casing at a constant level, an overflow aperture that regulates the thickness of the film, a vacuum pump, a scraper to remove the film of dried milk from the revolving drum and an evacuated receiver for the dried substance.

The milk is drawn into the drum casing or vacuum chamber by the force of the vacuum in this chamber. By the proper adjustment of the feed valve and the overflow valve, the milk rises to a given level and stays at that level while operation is in progress. The revolving steam-heated drum slightly dips into the milk in the vacuum chamber and picks up a film of milk which dries under reduced pressure while the drum makes one revolution. The dried film is removed by the automatic scraper and the finished dried milk is discharged into the receiver, while the moisture-laden air and vapor escape through a condenser located outside of the drying apparatus.

The temperature in the vacuum chamber during drying ranges from 40 to 55°C. (104 to 131°F.), depending on the relative completeness of the vacuum maintained. These drums are capable of drying from 3,500 to 4,000 pounds of fluid milk per hour. For the drying of large volumes, pre-condensing of the milk is recommended.

The Ekenberg Process.—This vacuum drum dryer was invented by Martin Ekenberg of Stockholm, Sweden, in the year 1899 and is covered by a number of United States patents, some of the earlier of which are patents No. 764,995, 1904, and No. 785,600, March 21, 1905.

The Ekenberg milk dryer is called an exsiccator. It consists of a revolving, steam heated nickel drum, inclosed in a vacuum chamber. The ends of the drum form bell-shaped bowls, dished outward. The drum is equipped with knives or scrapers, which remove the film of dried milk that gathers on the drum. Attached to the vacuum chamber there is a smaller chamber which serves to receive the dried milk as it is scraped from the drum. This is separated from the large vacuum chamber by a series of air locks, so that the material may be removed without breaking the vacuum in the large chamber.

The milk, as it enters the vacuum chamber, is sprayed into the concave ends of the drum. In this manner it is fore-condensed. It is then withdrawn from the vacuum chamber by a pump, and returned again, this time being sprayed upon the periphery of the drum.

After the dried milk is removed from the exsiccator, it is placed in a special drying chamber at a temperature of 90°F. where it remains long enough for the milk sugar to crystallize. This is usually accomplished in about an hour. After this it is ground, sifted and packed, ready for the market.

The Govers Process.—This process and equipment was invented and patented by Francis X. Govers, of Owego, New York, U. S. patent No. 939,495, November 9, 1909.

In the Govers patent the milk is dried on two revolving, hollow cylinders (5) located at such proximity to each other that the surfaces of the two cylinders are practically in contact with one another, similarly as in the case of the Just process. These revolving cylinders, however, are inclosed and operated in an outer casing which serves as a vacuum chamber (2), which connects with a vacuum pump through pipe (27). There is a milk supply tank (1) with regulating valve (4), feeding the milk to the vacuum chamber through pipe (3). Plates (10) which bear against the opposite ends of the cylinders (5) form with the revolving cylinders a receptacle (13) to receive and retain a small quantity of the milk to be desiccated. The cylinders are charged with hot water through pipes (16). Scrapers (21) remove the dried milk from the cylinders, and a rotating valve arrangement (28 and 29) is provided to catch the dried milk as

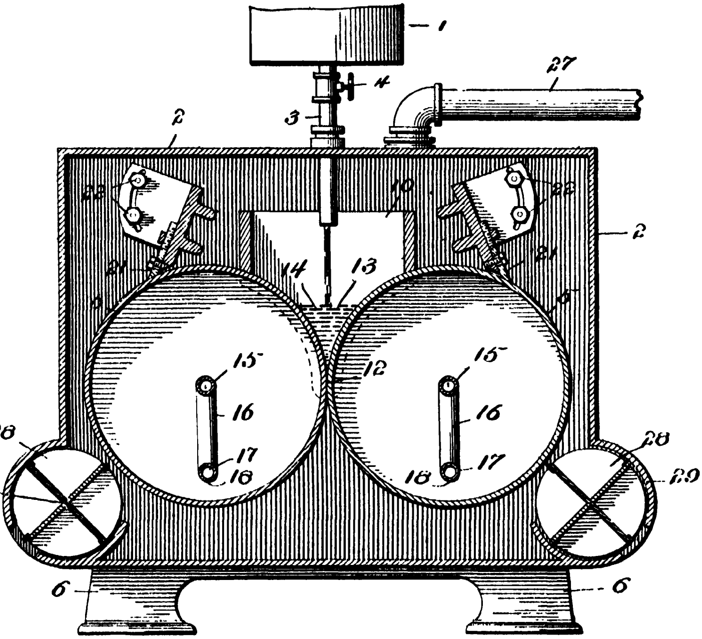


Fig. 126. The Govers vacuum drum dryer

it is scraped from the cylinders and to carry it from the vacuum chamber without breaking the vacuum.

In the operation of this machine it is aimed to maintain a partial vacuum, sufficient to cause the milk to boil at a temperature of about 157°F. Through the revolving metal cylinders passes a continuous flow of hot water at a temperature somewhat higher than 157°F. but below 212° F., so that the milk is never exposed to an excessively high temperature heating surface.

In the small receptacle of milk at (13) to which the milk is continually supplied from the outside, and as rapidly as it evaporates, the milk is heated to about 157°F. by the revolving cylinders. It is partly condensed and a thin film of this condensed milk coats the surface of the cylinders where it dries. The dried film is removed from the cylinders by the scrapers (21) and discharged to the outside of the apparatus through the vanes of the four-winged valves (28), located near the bottom on both sides of the vacuum chamber.

The Buflovak Drum Dryer.—The principle of drying milk and other liquids on a steam- or hot water-heated revolving drum in vacuo has been put to extensive application through the activities of the Buffalo Foundry & Machine Company, Buffalo, N. Y. The Buflovak dryer consists of a vacuum chamber, containing a steam-heated drum which turns in Sumet Bearings provided at both ends of the dryer. The main body of the liquid milk is held in a large reservoir in the bottom of the vacuum chamber from which it is continuously pumped to a shallow pan directly below, and close to the drum surface. A slight pressure is maintained in this pan. This tends to force the milk against the surface of the revolving drum. This device, in combination with others, assists in maintaining a film of uniform thickness.

The dry milk is removed from the drum surface by means of a knife, located at the opposite side of the drum, so that the greatest possible surface of the drum is utilized for actual drying. Running parallel to the drum is a spiral conveyor into which the dry milk falls and is carried to the receivers. Two receivers are provided, one at each end of the conveyor. When one receiver is full, the conveyor can be reversed and the second receiver is filled while the first is being emptied, thus permitting of continuous operation without breaking the vacuum. The

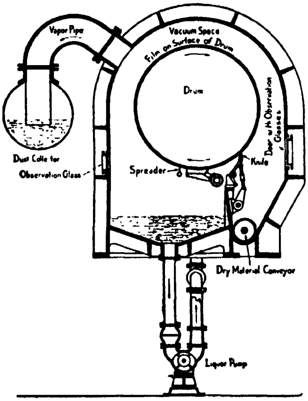


Fig. 127. Buflovak vacuum drum dryer

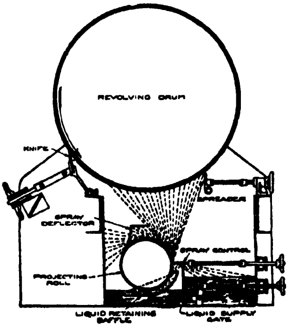


Fig. 128. Buflovak vacuum spray drum dryer

Courtesy of Buffalo Foundry & Machine Co.

escape and loss of any milk dust entrained in the exhausting vapors is prevented by a liquid-sealed dust collector attached to the dryer.

The Buflovak Vacuum Spray-Film Dryer.—This film dryer differs from other machines of the film-drying type by the manner in which the milk reaches the surface of the revolving drying drum. The milk is sprayed on to the drum by means of a threaded, revolving, projecting roll.

The spray-film dryer works exceptionally well on materials which seem to be repelled by heated surfaces, because this type of spray projection effectively impinges a coating on the heated drum. Malt products are a notable example of liquids of this nature. Spray film dryers, however, are not so well adapted to the drying of milk because the projection of a spray fails to insure a milk film of uniform thickness.

FLAKE FILM DRYERS

The principle of this type of film dryer consists of the use of pre-condensed milk of high concentration, which is spread upon a continuous wire mesh belt. The belt travels through a heated chamber or tunnel in which the drying is accomplished by heated air and without contact of the milk product with hot metal surfaces. The dried milk is removed from the belt by mechanical fingers or brushes. The finished product is in the form of fine flakes.

The available literature divulges two types of flake film dryers, namely, one designed and patented by the Borden Co., U. S. A., and the other by George Scott & Son, Ltd., London, England.

The Borden Flake Film-Drying Process.—The guiding aim of the design of equipment and method of operation of this process is to produce a powder of high solubility, and particularly, one that is capable of dissolving with maximum rapidity. This is accomplished by conducting the drying process in such a manner as to produce a highly porous, flake-shaped grain that offers maximum surface area of contact with the solvent—the water.

To this end the milk is first condensed to a high degree of concentration, reducing it to approximately one-fourth of its original volume. The concentrated milk is then cooled and whipped to a light, fluffy consistency. The fluffing is accomplished in a horizontal rectangular container equipped with a horizontal, revolving shaft that carries a wooden dasher similar to the revolving dasher in the old horizontal barrel dash churn, in which the barrel is stationary and the dasher revolves. The dasher moves slowly through the thick milk, causing the dasher boards or sticks to tear the semi-solid milk into loosely hanging films and shreds. Simultaneously, heated air is blown through the mass, which intensifies the swelling. This treatment and the flow of milk through the rectangular container is made continuous by the presence of partitions which divide the container into several compartments. The partitions are equipped with a port hole with shutter, allowing the milk to pass through each compartment and untreated condensed milk to enter the first compartment as soon as the latter has discharged its treated contents into the second compartment. The whipping and air incorporating treatment is continued in each succeeding compartment, so that when the milk reaches the last compartment it has become swelled to approximately double its original volume.

This fluffy, porous milk is then fed on to a continuous wire mesh belt which travels through an air-heated tunnel, where the drying is completed. Hot air passes both over the drying milk and under the belt, enhancing the drying of the porous milk coating. By the time the milk reaches the end of the tunnel it has surrendered all of its removable moisture, and the dried milk is removed from the belt by mechanical fingers, in the form of fine milk flakes.

This product, because of its porosity, dissolves rapidly, and because of absence of contact with high-temperature, metallic heating surfaces, possesses a high degree of solubility. On account of its profuse air incorporation, however, this process is not suitable for drying milk containing any considerable percentage of butterfat, such as part-skimmed milk, whole milk, or cream, as the fat yields readily to the oxidizing action of the air and causes the development of tallowy flavor. This process is particularly suited to the manufacture of a high quality, readily soluble skimmilk powder.

The Scott Continuous Vacuum Band Dryer.—In the construction and operation of this band film dryer, porosity of the finished product is not contemplated. Its similarity to the Borden flake film dryer is confined to the use of highly pre-concentrated milk, dried on endless metal belts or bands traveling in the heated drying chamber.

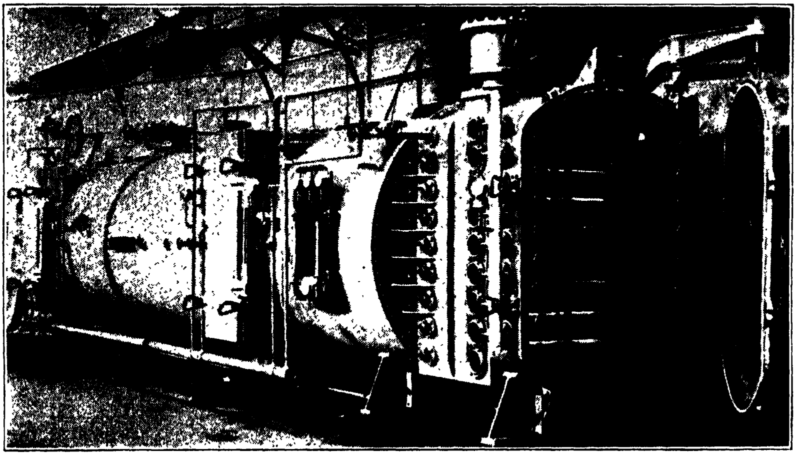


Fig. 129. The Scott continuous vacuum band dryer
Courtesy of George Scott & Son, London

The latest improved design of the Scott Dryer, British Patent No. 345,302, as shown in the accompanying illustration, consists essentially of a large horizontal metal drum which constitutes the drying chamber. The interior of this shell is equipped with a plurality of endless woven wire bands which are caused to travel from end to end of the drying chamber by means of two series of revolving rollers. These woven wire bands are constructed of tinned phosphor bronze, monel metal, or nickel. The upper run of each conveyor belt or metal band extends and travels over a hot plate containing numerous sections with independent inlets of the heating medium, making possible the application of different degrees of heat at different stages of the drying process. The drying chamber operates under vacuum.

The milk is first pre-condensed in a forced circulation evaporator to a concentration of approximately 50 to 55% milk solids. It is then flash-cooled and delivered, by means of a special rotary pump, upon the conveyor bands. The concentrated milk is spread across the width of each of the endless metal bands from a series of small-diameter stainless steel tubes, so arranged as to give a number of streams of milk which coalesce into an unbroken sheet covering the metal bands. This milk film on top of the traveling metal band is thus carried through the drying chamber over the hot plates which are heated by steam or hot water. During this passage from one end of the dryer to the other the milk is dried into a cake which separates readily from the metal band at the dry end, is broken up, and passes through a discharge gate into the upper one of a pair of receiving hoppers.

The removal of the dried milk from the traveling metal band is facilitated by mechanical scrapers. The milk, because of its viscosity, does not enter the mesh of the metal band, but lies on the surface and, therefore, does not come in direct contact with the hot plate. The independent inlets of the heating medium to different sections of the hot plates make possible the control of the intensity of heating at different stages of the drying process.

The Scott drying unit further provides a hopper for grinding and one for sifting, both operated under vacuum. The drying takes place under a high vacuum (approximately 29″) insuring low temperature in the entire drying unit. The milk powder can be discharged intermittently through the lower hopper without breaking or affecting the vacuum in the drying chamber, thus permitting of continuous operation. The dried milk can be packed and sealed under vacuum before the container is brought into the atmosphere.

This process differs in one important essential from the Borden process in that it not only does not propose to produce a highly porous product, but, operating under vacuum, its effect is to eliminate air instead of incorporating it. Since absence of air tends in the direction of delaying damaging fat oxidation, this process promises to be especially suitable for use in drying milk rich in butterfat. This process has the further advantage of facilitating the handling of milk pre-condensed to an unusually high concentration and, as in the Borden flake film process, the complete absence of contact of the drying milk with high-temperature metal heating surfaces, assists in yielding a product of high solubility.

CHAPTER XXIX

THE SPRAYING-DRYING SYSTEM

The principle of this system of drying milk is that of reducing the milk or milk product to an exceedingly fine spray or mist in the presence of currents of heated dry air. The minute particle size of this finely divided milk presents an enormously large evaporating surface, which readily and quickly surrenders its moisture to the hot air, and the milk particles deposit on the sides and bottom of hot air chamber in the form of dry milk flakes.

Similarly as in the case of the film-drying system, the spray-drying system did not originate with the milk drying industry. The principle of dehydrating fluid substances by atomizing them into an atmosphere of heated air dates back to the year 1872, but it was not until 1901 that it was specifically applied to the drying of milk. From that time on, however, its possibilities as a means to convert milk into powder form were subjected to extensive study which resulted in the invention of equipment and methods suitable for commercial manufacture. These early attempts were followed by further development of various types of equipment with improved accessories and methods of application, some of which have reached a remarkable degree of perfection from the standpoint of efficiency of operation, ratio of recovery, low moisture content, solubility and quality of the finished product.

General Description of Process.—The fluid milk is heated to a temperature of approximately 140 to 165°F. Formerly, the heated milk, as such, was atomized, but today it is first concentrated in the vacuum pan or by other means, thus removing a considerable portion of the water before atomizing. The condensed milk is then sprayed under pressure or by centrifugal force into the drying chamber. The drying air is drawn from the atmosphere, through a filter, into an air heating vault, where it is heated to a temperature of from 200 to 300°F. Upon entrance into the drying chamber, it mixes with the mist of atomized milk, diffusing through the chamber and dehydrating the milk. The bulk of the dried milk drops to the bottom of the chamber, and the fine milk dust which escapes with the outgoing air currents is recovered in a dust collector, usually consisting of filter bags, or the entrained milk dust is recovered by passing the outgoing air containing it through a spray of incoming fluid milk. The dried milk is removed from the drying chamber either continuously by an endless carrier or after the completion of the day's run. It is usually packed into air-tight, moisture-proof containers with or without further treatment, such as bolting and sifting.

DESCRIPTION OF SPRAY-DRYING INVENTIONS AND PROCESSES

The invention of drying fluid substances by atomizing them into an atmosphere of heated air was made by Samuel R. Percy, recorded in 1872. Since the date of this invention, numerous methods of applying the principle revealed by Percy have been developed, patented and commercially applied. The more basic patents that have found wide commercial application in this country and abroad are briefly described below:

The Percy Process.—This process was invented and patented by Samuel R. Percy of New York City, U. S. patent No. 125,406, April 9, 1872. The process embraces in its claims, a method of atomizing and desiccating fluid and solid substances, also any viscid substance containing water, by the use of dried, heated or cooled air or gas, which forces the substance into atoms; the atoms are thrown forward, and forced into a chamber and dried in consequence of the dried or heated air which propels them into the chamber and also, owing to the dried and heated state of the chamber into which they are thrown.

The Stauf Process.—The Stauf process represents the first commercially successful application of the desiccation of milk by the spray-drying principle invented by Percy. The Stauf process was patented by Robert Stauf of Posen, Germany, U. S. patent No. 666,711, January 29, 1901.

The patent claims are as follows: "The process of obtaining the solid constituents of liquids, such as blood, milk and the like, in the form of powder, said process consisting in converting the liquid into a fine spray, bringing such spray or atomized liquid into a regulated current of heated air, so that the liquid constituents are completely vaporized, conveying the dry powder into a suitable collecting space away from the air current, and discharging the air and vapor separately from the dry powder."

The Stauf patent shows a vertical drying chamber (e) into which the liquid (milk) to be desiccated is atomized through jets or nozzles (b) under pressure, into a fine spray. A current of heated air is admitted at the bottom of the drying chamber (f) running in the same direction as, and mixing with, the spray of milk, and evaporating the watery constituents of the spray. The steam and dried particles are carried upward by the heated air, retaining the atoms momentarily in the current of hot air and causing them to surrender substantially all the remaining moisture in the form of vapor, and the product is prevented by the cooling effect of such evaporation from undergoing chemical change. The vapors and dried atoms are guided by a cone (g)

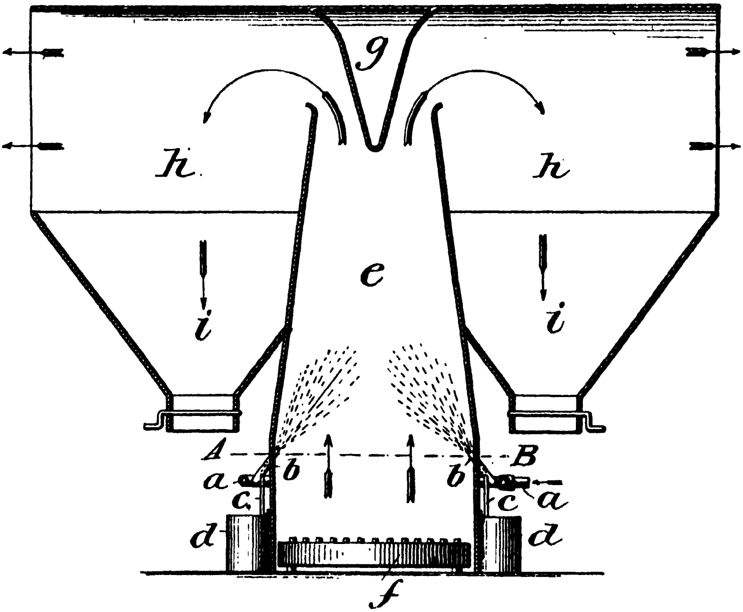


Fig. 130. The Stauf spray dryer

extending downward from the top into the drying chamber, into collecting chambers (h) where the desiccated milk or dry powder gathers in hoppers (i) away from the vaporizing current. The moisture-laden air or gas is separated from the dry powder and escapes through the sides of the collecting chamber, which consist of mill gauze, woolen fabric or like pervious material.

The McLachlan Process.—This process was patented by John C. McLachlan of Chicago, Ill., U. S. patent No. 806,747, December 5, 1905. This process is a modification of the Stauf process.

McLachlan uses a tall vertical drying chamber (B) surrounded on its sides by a jacket or casing (A), containing steam heating coils (G) with intake, and outlet of steam; a circular, perforated pipe (M) is installed near the top of the chamber for the purpose of discharging into the chamber heated air, an atom-

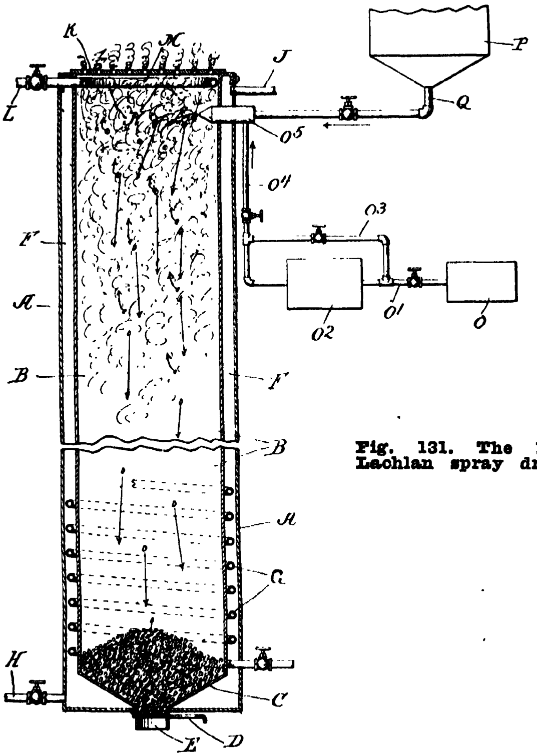


Fig. 131. The McLachlan spray dryer

izing jet (O^5) enters through the side of the drying chamber near the top, an air pump (O) forcing heated air into the atomizing nozzle (O^5), a slide door (D) at the bottom of the drying chamber for the discharge of the dried powder through opening (E), and a perforated covering (K) over the top of the drying chamber for the escape of the moisture-laden air.

In this apparatus the spray of the milk enters into the upper part of the drying chamber and is permitted to drop through an atmosphere of heated air. As the atoms of drying milk descend, they surrender more and more of their moisture and at a certain point toward the bottom they have discharged substantially all their moisture and are deposited in the form of a dry powder in the bottom of the drying chamber, from where they are discharged by a slide door. In the meantime the vapors pass freely up and out of the upper or open end of the chamber.

This process differs from the Stauf process essentially only in the fact that the milk descends through an atmosphere of heated air and that the drying chamber and the collecting chamber are one and the same, while in the Stauf patent the milk spray ascends and is carried into separate collecting chambers.

In a later design, U. S. patent No. 1,038,773, September 17, 1912, McLachlan causes the heated air to be forced into the drying chamber through a rotating discharge head located in the center of the drying chamber. The rotating discharge head directs the air currents radially outward toward a deflecting ring.

The milk is blown into the drying chamber through multiple supply nozzles or atomizers. These supply nozzles enter through the periphery of the deflecting ring. They discharge in a horizontal plane and incline to the radius in such a manner as to cause maximum commingling of the finely divided particles of the milk with the heated air. The dried powder deposits in the bottom of the drying chamber, a belt conveyor discharges it into a screw conveyor pocket, whence it is removed to any suitable storage container.

The moisture-laden air leaves the drying chamber through drums near the bottom and top of the drying chamber. These discharge drums are equipped with suitable arrangement to recover such parts of the powder as are deposited on their surfaces.

The Merrell-Merrell-Gere Process.—This process is similar to the Stauf process except that the patent covering the Merrell-Merrell-Gere process specifically refers to the desiccation of previously condensed milk, while the Stauf patent makes no specific reference to the use of condensed milk, although the term "milk" may have been intended to embrace all kinds of milk regardless of the degree of concentration prior to desiccation.

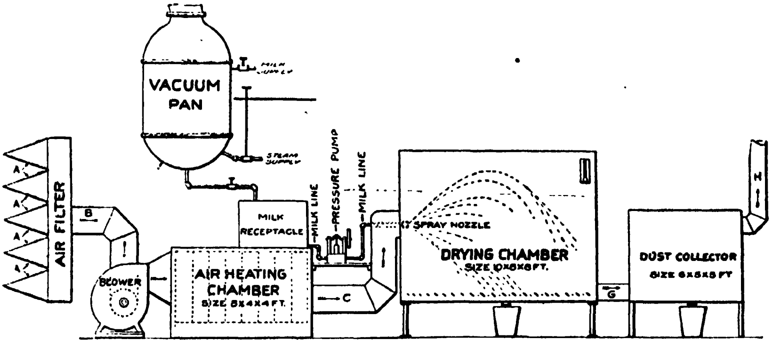


Fig. 132. The Merrell-Soule spray dryer

The Merrell-Soule Co., of Syracuse, N. Y., purchased the Stauf patent in 1905 and two years later L. C. Merrell, I. S. Merrell and W. B. Gere, of Syracuse, N. Y., assignors to Merrell-Soule Co. patented the process as applied to desiccating condensed milk, U. S. patent No. 860,929, July 23, 1907. Their patent claims read as follows:

1. "The process of obtaining the solid constituents of liquids and semi-liquids, in the form of powder, which process consists in concentrating the substance by removing a large percentage of the water therefrom, converting the concentrated mass into a fine spray, bringing such spray into a current of dry air or gas having an avidity for moisture so that substantially all the remaining liquid constituents are separated thereby, conveying the dry powder into a suitable collecting space away from the air or gas current, and discharging the air or gas separately from the dry powder.

2. "The process of obtaining the solid constituents of liquids and semi-liquids, in the form of powder, which process consists in concentrating the substance by removing a large percentage of water therefrom, converting the concentrated mass

into a spray, bringing such spray into a current of dry heated air or gas having an avidity for the moisture of the substance treated, retaining the atoms momentarily in said current so that substantially all the remaining moisture is converted into vapor and the product is prevented by the cooling effect of such evaporation from undergoing chemical change, conveying the dry powder into a suitable collecting space away from vaporizing current, and discharging the air or gas separately from the dry powder."

To the inventors of the Merrell-Merrell-Gere process belongs the credit of developing the spray-drying of milk into a commercially successful business. They were the pioneers of the industry of spray drying milk, and it is their early efforts to perfect the practicability of the process and to improve the quality and keeping properties of the product that gave the manufacture of quality milk powder and the appreciation of its value on the part of the consuming public a tremendous impetus.

The C. E. Rogers Process.—This process was patented by Charles E. Rogers of Detroit, Mich., U. S. patent No. 1,226,001, May 15, 1917, and No. 1,243,878, October 23, 1917.

A large circular drying chamber is provided. The pressure-milk line, fed by a Triplex pressure pump, extends around the entire periphery and the laterals that supply the spray nozzles enter the chamber on all sides. The spray nozzles are located about four feet from the top of the chamber, spraying the milk radially toward the center and permiting the atomized milk to drop from top to bottom of the drying chamber.

The air is drawn through air filters and then through a heat exchanger of the regenerative heater type, in which it is preheated by the outgoing warm air. From here a fan forces the preheated air through the air heating vault where it passes over fin-type heating coils. Approximately one-third of these coils may use exhaust steam, while the balance of the coils are supplied with high pressure steam to attain the high final temperature desired. The heated air, at a temperature of 180 to 200°F., enters the drying chamber near the bottom in the center of the chamber, rises through the falling mist of milk and leaves the chamber near the top, passing downward on the outside of the chamber into the screening or separating vaults which are equipped with cloth filter bags for reclaiming the entrained milk dust. From the screening vaults the air is drawn through an exhaust fan to the regenerative preheater of the incoming air, and then escapes to the atmosphere.

As shown above, in the Rogers system the heated air and the milk spray in the drying chamber travel in counter-current, the milk being atomized near the top drops to the bottom, and the hot air, entering at the bottom, rises through the falling mist of milk and escapes at the top. This facilitates maximum exposure of milk particles to hot air, enhancing rapidity of evaporation. It likewise causes the milk at its driest stage (near the bottom of the drying chamber) to come in contact with the driest air (at the hot air intake), thus making for completeness of drying and low moisture content of finished product. The air leaving the drying chamber near the point of intake of the milk causes the most humid air to contact with the wettest milk, thereby enhancing the completeness of moisture saturation of the outgoing air, and the regenerative air heater assists

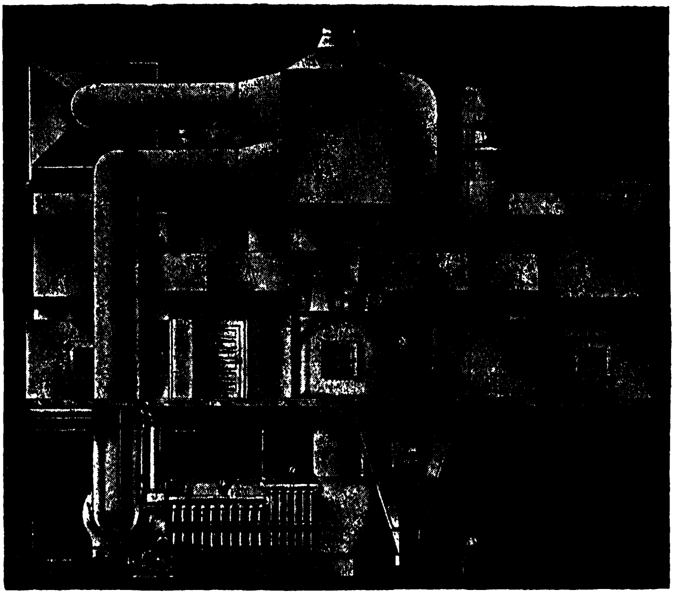


Fig. 133. The Rogers spray dryer
Courtesy of C. E. Rogers Co.

in reducing the loss of heat contained in the outgoing wet air to the minimum. Finally, the humid air leaving the drying chamber at the top is turned downward on the outside of the chamber. This reduces the velocity at which it passes through the filter bags to approximately two and one-half feet per minute and encourages the release from the air stream of a considerable portion of the entrained milk particles before reaching the filter bags.

In the Rogers dryer, similarly as in the Merrell-Soule process, the dried milk collects on the bottom of the drying chamber and remains there until the completion of the batch when it is removed by pushing it into a hopper.

The Gray-Jensen Process.—This process was invented and patented by Chester Earl Gray, Eureka, Cal., and Aage Jensen, Oakland, Cal., U. S. patent numbers 1,078,848, November 18, 1913, and 1,007,784, August 18, 1914. Aside from the above two basic patents there are three supplementary inventions, U. S. patent numbers 1,157,935, October 26, 1915 (Gray), 1,266,013, May 14, 1918 (Gray) and 1,392,656, October 4, 1921 (California Central Creameries). All five patents are made applicable under the Gray-Jensen process.

The apparatus, now known as the Gray-Jensen process and used under the Gray-Jensen patents is illustrated in Fig. 134. It consists essentially of one or more fluid milk storage tanks in which the milk is pre-heated by circulation through a continuous heater; a pre-heating chamber in which the milk is sprayed into the hot air escaping from the drying chamber; a cone-shaped drying chamber with intake of milk and heated air, outlet of heated air and dried milk, and traveler with chain links for rattling down the dry powder; a Ramshorn blower; a dried milk collector; a standard Rotex flour bolter; a hopper feeding the dried milk barrel; a shaking device for settling the dried milk in the barrel; and an air heating vault.

In the operation of the Gray-Jensen process the fluid milk is heated to a temperature of about 160 to 170°F. by continuous circulation from storage tank through flash heater and return until the desired temperature is attained.

It is then pumped into the collector or pre-heating chamber through a series of spray nozzles suitably distributed to cause

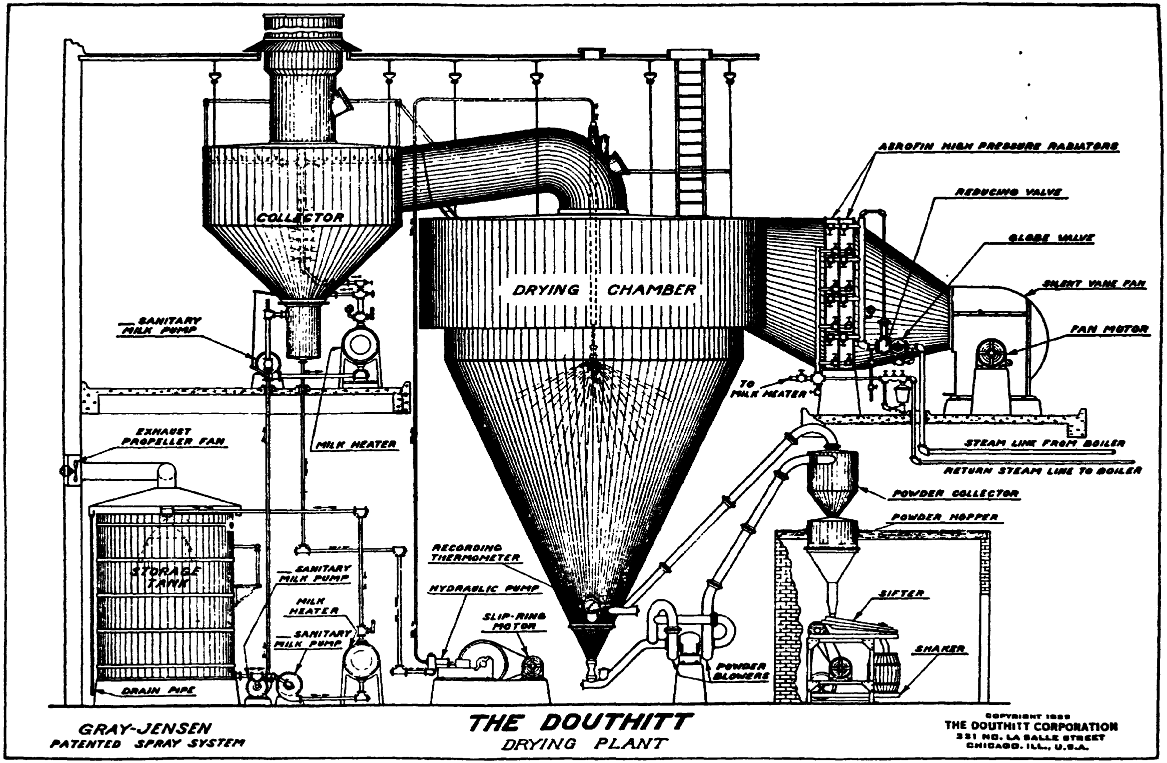


Fig. 134. The Gray-Jensen spray dryer
Courtesy of The Douthitt Corporation

the incompletely saturated air escaping from the drying chamber to pass through a finely divided spray of the milk. The air at this point has a temperature of about 160°F.; it escapes to the outside through a large exit in the center of the top of the pre-heating chamber at a temperature of about 122°F. On account of rapid evaporation of moisture, the milk surrenders some of its heat, lowering the temperature of the milk that collects in the cone-shaped bottom of the pre-heating chamber. In order to avoid the possibility of acid development in the milk at this point due to the activity of thermophylic bacteria, the milk is recirculated through a flash heater whereby a temperature of about 165°F. is automatically maintained. The spraying device in the pre-heating chamber operates in a manner similar to a revolving lawn sprinkler. The milk enters through the bottom under considerable pressure and this pressure causes the spraying device to revolve. The spray jets are so arranged as to cause the milk to strike the top and sides. This aids in washing down any adhering particles.

From the pre-heating chamber the milk is pumped under approximately 2,500 lbs. pressure into the drying chamber. It enters this chamber through the top, issuing forth from a revolving spray jet located in the center of the upper part of the drying cone.

The air is heated in a vault by steam coils or electric heating arrangement. At the entrance of the vault is installed an air blower that forces the air from the outside through the vault, and from the vault the heated air enters the drying chamber peripherally in a tangential direction. The tangential entry of the heated air into the circular chamber sets up a cyclonic current therein, and this effect is augmented by introducing the air at several different points through tangential openings.

The atomized milk thus enters at the center of the cyclonic air current and partakes of the rotary movement of the air current but, because of their greater specific gravity, the particles of drying milk influenced by centrifugal force are caused to travel in spiral lines outwardly through the current of air and are finally arrested by the confining, steeply-sloping walls of the chamber down which they fall to the discharge end at the bottom. The air which enters the drying chamber at its periphery at a temperature of about 260°F., escapes through the center of the top into the pre-heating or pre-condensing chamber at a temperature of about 160°F.

The continuous and complete removal of the dry powder from the sloping sides to the point of discharge is further facilitated by the revolving traveler with chain links, which "rattle down" the powder. The dried milk is sucked from the bottom of the drying chamber by means of a blower with Ramshorn pipe arrangement which causes it to be reduced to a powder of uniformly fine particles. The blower conveys it into the collector from which it feeds the hopper. From the hopper it passes through a standard Rotex flour bolter into the final package—the barrel—which rests on a shaking platform, thus facilitating the settling and packing of the powder as a continuous operation in the finished container.

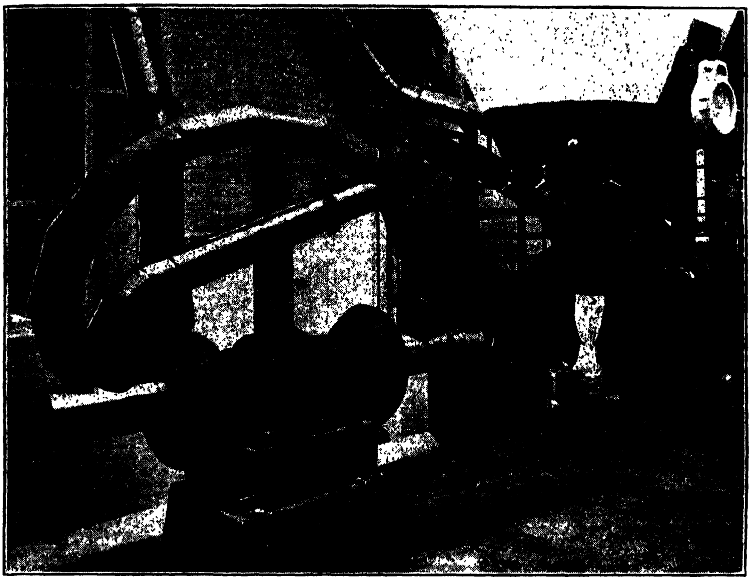


Fig. 135. Ramshorn pump
Courtesy of The Douthitt Corporation

The distinctive and highly advantageous features of this process and its results are:

1. **Exhaustive Removal of Moisture.**—The exhaustiveness

of the removal of moisture from the particles of milk is augmented by the fact that the heated air, moving through the spray of milk spirally toward the center, where it escapes, has taken up its maximum charge of moisture by the time it reaches the center, which is the point of its discharge and it is driest near the periphery. The spray of milk being discharged into the cyclonic current at the center, carries its maximum moisture content at that point, gradually surrendering it to the air, as it moves outward to the periphery of the cyclonic current. The completion of the drying is accomplished in the zones of incoming heated air which carry the least humidity. Therefore, as the outwardly moving particles of milk surrender more and more of their moisture, they pass through drier zones of heated air. This obviously both accelerates the speed of drying and enhances the completeness of the removal of moisture.

2. **Preservation of Solubility.**—Inasmuch as the danger of the solubility-destroying effect of heat is greatest while the milk is still in the liquid state, and this effect is practically completely absent in milk from which the bulk of moisture has been removed, this process has the additional advantage of maximum preservation of the solubility in the finished product. The temperature of the cyclonic air current is lowest when it reaches the center where the moisture content of the milk is greatest. By the time the particles of milk come in contact with the hottest air (at the periphery) their moisture content is lowest.

3. **High Per Cent Recovery.**—This process makes possible maximum recovery of the milk powder. The moisture-laden air escapes in the center, where the particles of milk are heaviest, and where their greater specific gravity causes them to partake of the centrifugal motion, moving them outward until when completely dried, they strike the steeply-tapered confining walls of the drying chamber and fall to the bottom of this chamber. Loss of milk dust with the escaping air is entirely prevented because the air discharged from the drying chamber passes through the spray of fluid milk in the pre-heating chamber, thereby surrendering to the fluid milk any particles of dried milk that might be carried over from the drying chamber with the escaping air, and making possible complete recovery.

4. **High Economy of Operation.**—This process insures

economy of fuel. The air enters the drying chamber at 260°F., it leaves the drying chamber at 160°F. and escapes from the preheating chamber to the outside at about 122°F. By utilizing the air that leaves the drying chamber for the heating and precondensing of the fluid milk the waste or loss of heat units is thus limited to the irreducible minimum.

5. Freedom from Recontamination of Finished Product.—The dried milk is transferred from drying chamber to the sealed package without exposure to the outside air. This insures protection against contamination with bacteria, insects and foreign matter of any description. It also prevents re-absorption of moisture from the air which is known to impair the solubility of the powder.

The Milkal Process.—This process and its equipment described by Scott,[211] is in operation in the Milkal factory, Hemyock, Devon, England. The name of the inventor and date of invention are not given. This spray dryer consists of a spacious drying chamber approximately 20 feet square and 33 feet high, terminating at its top in a truncated pyramid. It has two hoppers arranged similarly to those shown in the original Stauf patent. The drying chamber widens at the bottom above the tapering hoppers to accommodate the base of the filter bags. The hoppers collect the milk powder from both the drying chamber and the filter bags. These hoppers extend down into the room below, removing the accumulating dried milk as far as possible from the heat of the drying chamber, and thus holding the temperature of the finished product low. The air is drawn through the system by a suction fan located at the air outlet from the drying chamber. The air heating vault is equipped with steam coils, and baffles to remove water entrained in the air entering from the washer, where it previously passed through a spray of water.

Both the heated air and the milk enter at the top. There are two milk atomizers, with the air inlet in the center between them. Atomization is accomplished by steam or compressed air in a vertical plane with no vortex effect, causing the milk spray to drop by gravity through the air stream. The arrangement of the milk inlet is such as to make contact with the heated air only after the spray has been completely dispersed. The milk is pre-condensed and cooled, and enters the drying chamber without preheating. The milk is therefore not heated until after it has been converted into atomized form. The milk particles mix evenly with the tranquil air stream and their even distribution subjects them to the same temperature in every zone of the drying chamber. The mechanically shaken filter bags return the fine powder that is entrained in the outgoing air continuously to the collecting hoppers where it mixes with the remainder of the milk powder.

The dried milk accumulating in the hoppers is withdrawn as required into cylindrical containers which are conveyed to the sieving and packing room. The powder is sifted through screens of a fineness of 50 meshes to the inch, into hoppers which deliver it into the final package. The quality of the powder, according to Scott, is of a high order and the solubility 100 per cent.

The Krause Spray-Drying Process.—This process was invented by Dr. George Alexander Krause, Munich, Bavaria. It was patented in Germany in 1912, patent No. 297,388, and later in many other countries. The novel feature that distinguishes this process from those previously described lies in the method of atomizing the milk. Instead of forcing the milk under high pressure through nozzles with minute orifices, Krause produces the spray by centrifugal force.

The drying chamber consists of a cylindrical vault (Trockenzylinder), in the center of which revolves a metal spray disc, operated by turbine or motor. This disc is either flat or saucer-shape and carries two or more radial discharge openings. It revolves at the high velocity of 5,000 to 20,000 R.P.M., the necessary speed varying with the diameter of the disc and the character and concentration of the liquid to be dried. With a disc measuring 50 cm. (20 inches) in diameter a maximum speed of 6,000 R.P.M. is used. This represents a peripheral speed of the disc of approximately 523 feet per second. The milk flows from the milk supply tank, located on top of the drying chamber, by gravity to the center of the spray disc, or it may enter through the bottom of the disc. The centrifugal force of the rapidly revolving disc causes the milk to spread toward its periphery, and from there it is thrown with great velocity into space in the drying chamber, becoming simultaneously atomized into a very fine mist-like spray.

The fresh air enters from outside through an air filter and passes through the heating vault. The heated air rises through a conduit into a drying dome located in the milk drying chamber. By means of a blower fan the heated air is drawn through the mist of atomized milk, where the milk is dehydrated while in the form of a comparatively thin, horizontal layer.

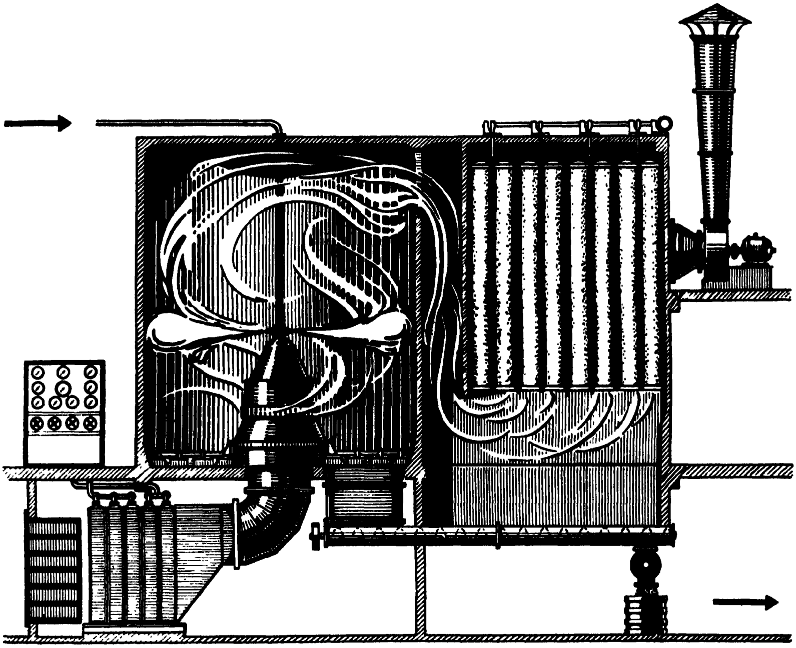


Fig. 136. The Krause centrifugal spray dryer
Courtesy of the American Lurgi Corporation

The bulk of the dried milk deposits on the floor of the drying chamber where a sweeper moves it continuously into a receiver from which it is discharged by means of a conveyor.

The moisture-laden air leaves the drying chamber near the top and is drawn through a series of intermittently shaking dust collectors for the purpose of recovering the entrained milk dust. From the dust collectors the air escapes through a blower to the outside. The Krause process is used with fluid as well as with precondensed milk.

The Krause milk dryer with its centrifugal atomizer has the outstanding advantage of permitting the use of highly preconcentrated milk, there being no small orifices and therefore no tendency to clog. This makes for increased drying capacity and fuel economy. This process does not require high milk pressure and it permits continuous operation over prolonged periods.

The Dick Process of Spray-Drying.—This process is the invention of Dr. S. M. Dick of Minneapolis, Minn. Patents were granted in 1919, U. S. patent No. 1,298,470; and in 1921, U. S. patent No. 1,374,555. The drying chamber is cylindrical and, similar to that of the Krause process, the milk is atomized by centrifugal force, by means of a revolving disc located in the center of the drying chamber near the top. The intake of the heated air and the exit of the moisture-laden air are so located and directed as to divide the air space in the drying chamber theoretically into four superimposed zones. Beginning at the top is the spraying and evaporating zone, then follows a dead air zone, below this lies the dehydrating or finishing zone and at the bottom the cooling and receiving zone.

A portion of the heated air enters into the top zone where it mixes with the centrifugal spray and causes initial evaporation. The remainder of the heated air enters into the third zone or the dehydrating zone, where the drying is completed. Between these two zones lies the dead air zone through which the partly dried milk drops and reaches the dehydrating zone. The moisture-laden air from the zones above and below the dead air zone is discharged through exits in the dead air zone. According to the patent description the temperature of the heated air used is surprisingly low, ranging between 150 and 168°F.

CHAPTER XXX

COMMERCIAL MANUFACTURE OF MILK POWDER BY THE SPRAY-DRYING SYSTEM

Pre-Heating the Milk.—One of the important advantages of the spray-drying system is that it makes possible the production of a milk powder that is practically 100 per cent soluble. The solubility of the finished product, however, is dependent on certain limitations of temperature to which the milk is heated before it reaches the drying chamber. Experience has shown that high preheating temperatures jeopardize the solubility of the milk powder.

In the majority of the spray-drying processes the milk is preheated before it reaches the drying chamber. While accurate data on the relative sensitiveness of fluid and pre-concentrated milk to heat are lacking, commercial experience appears to have established the conclusion that it is good practice to hold the preheating temperature down to 160° F. or below. Accordingly, the practice that has been generally adopted in plants using the spray-drying system is to preheat the milk to temperatures ranging from 140 to 160°F. In some processes, however, a slightly higher preheating temperature (170°F.) is used without noticeable damage to the solubility of the resulting powder. If the milk is condensed before drying, similar temperature limits should be observed in forewarming and condensing.

From the standpoint of rapidity and completeness of drying, it would appear advantageous to pre-heat the milk, but comparative data on this are not available. Information on the relative economy of operation is likewise lacking.

Pre-Condensing the Milk.—In the early days of spray-drying, the fluid milk was dried without pre-condensing. On account of the high percentage of water in the milk (87.6% in whole milk and 91% in skimmilk), this practice placed a very high evaporative duty on the drying equipment, greatly limited the output of the finished product, necessitated larger installations and required long hours of operation. It had the additional drawbacks of bulkiness of powder, low recovery and difficult miscibility of the product. These experiences suggested the great advantages of pre-condensing the milk before drying, and led to the general adoption of the practice of pre-condensing, which is now used in the manufacture of the bulk of the powder made by the spray-drying system.

On the basis of fuel economy alone, the greater the amount of water removed before the milk reaches the drying chamber, the more economical the operation. The point to which milk is pre-condensed varies widely according to process of spray-drying.

The extent to which milk may be pre-condensed depends, aside from the factor of thermal economy, on mechanical limitations, such as the mechanics of vacuum pan operation and of atomizing. There is a limit of concentration beyond which the viscosity of the milk is so great that its handling in the evaporator becomes unmanageable. Likewise, the type of atomizer must be considered. In the operation of the pressure spray, pre-condensing to a concentration greater than 4 or 4.5 to 1 is usually not contemplated and may not be practicable on account of trouble from clogging. The centrifugal atomizer, as used in the Krause process and the spray nozzles involving the use of compressed air, on the other hand, are capable of satisfactory atomization of milk of higher concentration. The advantages of pre-condensing are briefly discussed in succeeding paragraphs.

Effect of Pre-Condensing on Economy of Manufacture.— The chief advantage of pre-condensing milk for spray-drying lies in greater economy and practicability of operation. The heat transmission coefficient of air is much lower than that of metal surfaces. This limits the economy of spray-drying in two ways; namely, through uneconomic utilization of the fuel required for heating the air, and through uneconomic utilization of the heated air in the drying chamber, the latter being due largely to the fact that in most spray-drying processes the spent air which still contains much heat (usually about 160°F.) escapes into the atmosphere and constitutes a considerable thermal loss. In the evaporator, on the other hand, direct contact of the milk with steam-heated metal surfaces (coils), and the high velocity of the heating medium (steam) on one side of the heating surface and of the liquid (milk) to be heated on the other, expedite heat transmission and evaporation, and the return of the steam condensate to the boiler makes for maximum fuel economy. The powder containing 3 per cent moisture, reports the following in spray-drying also are greater than the power requirements for vacuum pan operation in pre-condensing.

Scott,[211] as the result of an exhaustive experimental study of the comparative fuel economy of spray-drying 2,000 pounds of whole milk per hour, containing 12 per cent milk solids, to a powder containing 3 per cent moisture, reports the following results on the steam and coal consumption, with and without pre-condensing respectively:

A. Milk not Pre-Condensed.

Fluid milk pre-heated in steam-jacketed heater to 140°F., and sprayed directly into drying chamber.

Air supply heated by steam coils.

Total steam requirements per hour,	3694 lbs.
Total coal consumption per hour, $\frac{3694}{8} =$	462 lbs.

B. Milk Pre-Condensed to 40 Per Cent Solids.

Fluid milk pre-heated to 140°F. as in A, and
Concentrated in vacuum pan to 40% solids.
Concentrated milk sprayed into drying chamber.
Air steam-heated as in A.

Total steam requirements per hour,	2401 lbs.
Total coal consumption per hour, $\frac{2401}{8} =$	300 lbs.

In the above test, pre-condensing to a concentration of 40% solids resulted in a saving of 38% of the fuel required, as compared with spray-drying an equal amount of milk without pre-condensing.

The economy of pre-condensing involves, in addition to fuel economy, economy of space and labor. It increases the capacity of the spray-drying equipment and reduces the time of operation. In fact, the large volume of fluid milk that must be taken care of in the drying chamber and the prolonged period of drying it without pre-condensing, render the spray-drying of fluid milk highly impracticable.

Effect of Pre-Condensing on Bulkiness of Spray-Dried Powder.—Milk powder made from pre-condensed milk is more compact and less bulky than that made from uncondensed milk. This difference is quite marked. The spray-drying of fluid milk yields a powder of exceedingly fine, porous, fluffy grains. Powder of this character refuses to pack closely together, it is bulky. Pre-condensed milk, on the other hand, produces a coarser and more granular powder. It is less bulky and packs more readily.

Effect of Pre-Condensing on Recovery of Spray-Dried Powder.—Because of its extreme fineness and fluffiness, spray-dried powder made without pre-condensing is readily entrained and renders efficient recovery difficult, even in the presence of a highly efficient mechanical dust collector. Unless the exhausted air from the drying chamber passes through a spray of fluid milk or other liquid which arrests the entrained milk dust and causes it to deposit, such as is provided by the Gray-Jensen process, entrainment losses of spray-drying without pre-condensing will be large and recovery unsatisfactory.

In the case of pre-condensed milk which yields a spray-dried powder with a coarser and less fluffy grain, there is less entrainment, the entrained dried milk is more readily reclaimed in the dust collector, and a more complete recovery is possible.

Effect of Pre-Condensing on Solubility of Spray-Dried Powder.—The effect of pre-condensing on the solubility of milk powders appears to be negligible provided that the temperatures used in forewarming and condensing are sufficiently low (not exceeding (160°F.) to preserve the colloidal equilibrium of the protein constituents of the milk. The spray powder made from fluid milk goes into solution somewhat slower at the start than that made from pre-condensed milk, as explained later under "Miscibility of Milk Powder."

Homogenization for Spray-Drying.—Nothing is gained by homogenizing in the manufacture of skimmilk powder. When using the pressure spray nozzle and with a milk pressure of approximately 3,000 lbs. or over, the spray-drying of pre-condensed whole milk exerts a homogenizing action. It is therefore not necessary to homogenize such milk. In the spray-drying of fluid, uncondensed milk, however, the homogenizing action of atomization is negligible. Hence, it is necessary to homogenize uncondensed whole milk before it reaches the drying chamber in order to avoid objectionable churning when reconstituting the powder. In the manufacture of cream powder, the cream is usually not precondensed. Therefore, the cream, after pre-heating to 145°F. or slightly above, is homogenized before it enters the drying chamber. Satisfactory homogenization is accomplished at 2,500 to 3,000 pounds of pressure.

Data showing the effect of homogenization on solubility and quality of the powder are lacking. It has been shown in Chapters XIII and XXII on "Homogenization of Evaporated Milk" and "Sterilized Sweet Cream," respectively, that homogenization lowers the heat stability of products with high concentration of solids, or of fat, or of both. This fact suggests a similar effect on solubility of the powder made from homogenized whole milk or cream. Commercial experience in milk drying, however, does not support this assumption.

HEATED AIR REQUIREMENTS IN SPRAY-DRYING PROCESS

The volume and temperature of the heated air, that will evaporate a given amount of water or that will dry a given amount of milk, vary with the temperature and humidity of the atmospheric air, the temperature and concentration of the milk to be dried and the temperature and degree of saturation of the moisture-laden air exhausting from the drying chamber.

Temperature of Heated Air.—Other things being equal, the consumption of heat in spray-drying decreases with the rise of temperature of the heated air. With air only slightly heated the expenditure of heat is very great, and large volumes of air, necessitating large drying chambers, must be used. Hausbrand[216] shows that with slightly heated air the expenditure of heat may be two to three times as great to evaporate a given weight of water as the theoretically needed calories. It is economically advantageous, therefore, to use the highest temperature of heated air that the liquid to be dried will stand without injury to its quality.

The maximum temperature of the heated air that the particles of milk will stand without injury to quality depends primarily on the rapidity of evaporation. The particles of milk are most sensitive to heat in the presence of moisture. In the dry state they are not readily overheated. Damaging overheating, therefore, is avoided by providing conditions that make for maximum rapidity of evaporation, such as is made possible by accomplishing the mixing of milk particles with the air in the presence of violent turbulence. This violent mixing brings the milk particles in contact with the air that contains but little moisture, causes almost instantaneous evaporation of the milk spray, and removes the moisture-laden air quickly from the freshly entering fluid milk particles.

For above reasons, spray-drying processes in which the air enters in such a manner as to mix with the milk spray in the form of a turbulent swirl, as is the case with the Merrell-Soule, the Gray-Jensen, the Krause and the Kestner processes, permit of the use of higher air inlet temperatures than processes that provide for tranquil air currents, such as the Rogers, Dick and Milcal processes.

For average conditions of milk and air dispersion, the air entering the drying chamber usually has a temperature of about 130°C. (266°F.). The increased rate of mixing air and milk spray in the Kestner process permits, according to Reavell,[213] air inlet temperatures as high as 200°C. (392°F.), while for the tranquil air current processes of Rogers and Dick, air inlet temperatures of 180 to 200°F. and 160°F., respectively, are recommended.

Effect of Atmospheric Conditions on Volume of Air Required.—The temperature of the heated air being the same, the weight of air required increases with the atmospheric temperature. Less air is required in cold weather than in hot weather. But the smaller quantity of cold air requires more calories to heat than the larger quantity of warmer air, in order to be raised to the same temperature. For economic operation, therefore, the heating surface in the hot air furnace or vault and the size of the equipment for circulating the air should be of such flexibility as to adjust operation to seasonal and weather conditions. The heating surface should be sufficient for maximum temperature of heated air on coldest days, and the air circulating system should be of sufficient size to carry the large quantity of air required on the hottest days.

It is obvious that, with the above flexibility provided, the blowing apparatus, while adequate when run at full capacity during the warm season, will be too large to run at full capacity in cold weather and, therefore, should be run below capacity at that time. On the other hand, the heating surface, while ample when run at full capacity during cold weather, is oversize in warm weather and only a portion of it should be used.

Velocity of Air.—For economical and proper heating of the air and satisfactory performance in the drying chamber the air should have the proper velocity. The amount of heat taken up increases with the velocity of the air current over the heating surface. High velocity, however, greatly increases the friction in the air conduits, requiring more power and decreasing the efficiency of the blowers; it reduces the water-absorption power of the heated air in the drying chamber and increases entrainment losses. In the conduits to and from the heating vault the velocity of the air should not exceed 10 feet per second and in the heating vault and drying chamber it should be limited to about 20 feet or less per second.

The weight of air per unit time has a variable volume due to heat expansion. It is obviously smallest at the intake of the heating vault, largest immediately after heating and intermediate when escaping from the drying chamber. Hence, in order to control the velocity of the air circulation throughout the drying unit properly, there must be proper correlation of dimensions of all air flues, conduits, and blower fan. from intake of cold air to exit of drying chamber.

Location of Suction Fan.—For mechanical circulation of air, as is used in the spray-drying of milk, it is easier to move small volumes than large. From the standpoint of mechanical conveyance of the air, therefore, it would be preferable to install the blower fan at the intake of the cold air to the heating vault, and this is, in fact, done in many installations. The next best location for the fan is at the exit of the drying chamber. The most unfavorable position is between heating vault and drying chamber. However, the fan causes slight vacuum at the suction end and slight pressure at the exhaust end. It is well known that vacuum (pressure lower than that of the atmosphere) in the drying chamber is advantageous to evaporative efficiency and economic expenditure of heat.

Effect of Barometric Pressure.—Variations in the atmospheric or barometric pressure also inflence the amount of air and heat required to some extent. Other conditions, such as humidity of air, being the same, an increase in barometric pressure decreases the amount of air required and enhances the economy of drying. The lower the barometric pressure, other conditions being the same, the more air and heat are required to dry a given amount of milk. This effect occurs only when the barometric pressure in the drying chamber is the same as that of the outside air, which in most instances of spray-drying of milk is the case. The effect, however, is slight, but its presence may explain some of the fluctuations in operating results that are encountered in commercial drying.

Effect of Humidity of Atmospheric Air.—The humidity of the atmospheric air also has a considerable effect on the drying efficiency and economy of the air. Atmospheric air always contains moisture. It is seldom, if ever, completely saturated, but the humidity of the air varies within wide limits. It usually increases with a rise in temperature. Since the chief duty of the air in the spray-drying system lies in evaporating water from the milk and absorbing this water, it is clear that the evaporative efficiency of the heated air decreases with an increase in the humidity of the atmospheric air.

Temperature and Saturation of Air Discharge.—Finally, the temperature and degree of saturation of the air discharged from the drying chamber influence the quantity of air and heat required for drying a given quantity of milk. As previously stated, the higher the temperature, the higher the point of saturation and the more moisture the air is capable of absorbing and holding. While heat is given off and the air escapes from the drying chamber at a temperature lower than that at which it entered, it must be sufficiently hotter at its exit from the drying chamber than at its entry into the heating vault to be capable of holding the water evaporated from the milk, together with the original moisture, without being in a state of supersaturation. In commercial practice the air leaves the milk drying chamber at temperatures ranging from 120 to 200°F.

AIR-HEATING VAULTS

The methods of heating the air for use in the spray-drying chamber are classified by Reavell[217] as follows: Heating by steam, by hot oil, by flue gas heaters, by direct fired heaters, and by electric heaters.

Heating by Steam.—In this method of air heating the steam is usually passed through sections of steam coils banked in a vault and the air to be heated strikes the coils preferably at right angles. The heat control is facilitated by equipping each coil section with a separate control valve. If exhaust steam is available it is used to advantage in the first section and high pressure steam is used only in subsequent sections where the air receives the final heating.

In some installations the heating arrangement is reversed, the vault serving as a steam chest in which the air passes through the coils. This system requires a heavy vault casing to withstand the high steam pressure, and unless copper air tubing is used there is danger of contamination of the air with scale.

The method of heating the air by steam has the advantage of compactness of heating unit, because of the high rate of heat transfer from steam to air. Because of its convenience this method has been adopted in the great majority of milk powder plants.

Hot Air Furnaces.—In this type of heater the air to be heated passes through tubes installed in a furnace. In the hot air furnace higher air temperatures are attainable and the theoretical fuel economy is greater than in the case of steam heating. In practice, however, this increased thermal efficiency is possible only when the escape of the gases at uneconomically high temperatures is prevented. The chief drawbacks of direct fire heaters are less complete temperature control, relatively rapid deterioration of the heating tubes when constructed of wrought iron or ordinary steel, and the danger of entrainment of foreign matter such as particles of scale or iron rust, etc., which menace the mechanical purity of the milk powder.

Heating by Circulation of Hot Oil.—This method represents an adaptation of the furnace by interposing an oil circuit between the furnace and the air. Reavell recommends this for heating air to temperatures higher than 270°F. Its advantages are that it provides a greater temperature difference and ease of temperature control, as against its disadvantages of lower rate of heat transfer than with saturated steam and the need of a special oil heating furnace and circulating pump.

Heating with Flue Gases.—Given a plentiful supply of flue gases at a sufficiently high temperature this method has the great advantage of maximum economy. The air to be heated is passed through tubes installed in the flue gas duct. In order to limit the necessary heating surface, velocity of air and gas are essential. To insure adequate velocity of the gas the installation of a fan for forced draught for the boiler may be necessary. Scott suggests as an economical arrangement in the case of a limited supply of flue gases the use of two series of air heaters, the first utilizing the available exhaust steam and the second utilizing the flue gas to attain the final air temperature desired.

Air Heating by Electricity.—Electricity is as yet an expensive form of heating medium. Unless local electrical power is unusually cheap and fuel of any kind scarce, the heating of the air by electric current is economically out of the question. It is conceivable, however, that in localities so favored as to be able to produce unusually cheap hydro-electric power, electric heating might become economically practicable.

Location of Heating Vault and Heat Insulation.—It is advantageous to so locate the heating vault as to obviate the installation of flues at its air intake and between the heating vault and drying chamber. It is important, further, to protect the entire system against avoidable thermal loss due to heat radiation, by proper heat insulation of the heating vault, air passage between vault and dryer, and the drying chamber itself.

Air Supply.—The air is supplied to the heating vault and drying chamber by means of a powerful blower or suction fan. A blower fan may be installed at the intake of the cold air to the heating vault, or a suction fan may be stationed at the air exit from the drying chamber, or the fan may be placed between heating vault and drying chamber. As already pointed out under "Heated Air Requirements," for ease of maximum conveyance the fan should be located at the intake of the cold air. However, if located at the exit of the drying chamber, the suction of the fan produces a slight vacuum in the drying chamber which makes for greater evaporative efficiency and economic expenditure of heat. Because of this advantage the suction fan at the exit of the drying chamber is often given preference over the blower fan at the intake of the heating vault.

Filtering the Air.—The cold air is drawn into the heating vault from the atmosphere. Efforts to dehydrate and re-use the moisture-saturated air from the drying chamber, thus utilizing the heat contained in the outgoing air, have so far not proved practicable.

Other than the partial utilization of the heat contained in the escaping air, either for pre-heating and pre-condensing the fluid milk as exemplified by the Gray-Jensen process, or for preheating the incoming air by passing the outgoing air through a regenerative air heater as is the case in the Rogers process, the heat contained in the air that escapes from the drying chamber is lost; it is not re-used for drying and the air supply to the heating vault consists exclusively of new atmospheric air.

The fresh supply of atmospheric air may be drawn through a filter located at the intake of the heating vault. Filtering is desirable to protect the milk powder from mechanical impurities in the air. The chief drawback of filtering through pervious material such as absorbent cotton lies in the extra load which the resistance of the filter places upon the suction fan. The use of this type of air filters in milk powder plants, though desirable, is not customary. In some plants, however, the air is washed by drawing it through a spray of water, or through a series of screens of wire mesh or gauze over which a film of water trickles. In such cases the entrained water carried over from the air wash may be trapped by a baffle arrangement in the heating vault. The water spray is limited in its efficiency as an air filter. It will not free the air from the greasy turbidity of the city atmosphere, but it is effective in filtering out the coarser mechanical impurities. Its chief disadvantage lies in the fact that the washing does increase the humidity of the air somewhat and on hot days this increase may be quite appreciable.

DRYING CHAMBER

The drying chambers installed in commercial milk powder factories vary in dimensions and shape, as well as in location and type of milk spray, location of intake of heated air, direction of air current, and location of exit of moisture-laden air. Many of the chambers are of the rectangular type. They measure from about 12 to 20 feet in length, with a height upward to still larger dimensions. Some are of circular type, resembling silos, and others are cone-shape, tapering downward. In the latter case, the continuous removal of the milk flakes which deposit on the sloping sides is facilitated by a revolving traveler of chain links which "rattle down" the dry powder. In some drying chambers the dried milk collects at the bottom and is removed only at the conclusion of the day's run. In others it is continuously drawn out by a suction pump or brushed on to a screw conveyor.

Position of Air and Milk Inlets and Air Outlet.—Hausbrand[210] points out that the heated air enters the drying chamber hotter than it leaves and usually its degree of saturation with moisture is greater at its exit than at its entry. The increasing density due to decreasing temperature and the increasing humidity of the air in its journey through the drying chamber causes the air to become heavier. Hence its inclination to travel downward. From the standpoint of the law of gravitation, therefore, the logical movement of the air current should be from top to bottom of the drying chamber. This arrangement, however, is not always feasible nor desirable. It is important that, as the drying particles of milk surrender more and more of their moisture, they come in contact progressively with increasingly dry air.

The heated air is usually driest at its entry and most saturated at its exit. The particles of dried milk drop to the bottom of the drying chamber and are from there discharged to the outside. If the air exit is also at or near the bottom, the discharge of the dried milk then would be at the point of greatest humidity of the air. This would not be conducive to maximum dryness of the finished product. It follows, therefore, that for best results the direction of the heated air and of the spray should be so arranged as to cause the incoming air (which is driest) to meet the milk particles at the point of their lowest humidity and to cause the outgoing air (which is most humid) to leave at the point where the milk is wettest (which is near the source of the spray).

The arrangement of air intake and outlet and of location of spray varies with the different methods of spray-drying and with different installations of the same method. Where the spray issues forth from nozzles located all on one side, the heated air often is admitted through a slot located directly under the spray nozzles and the air travels in the same direction as the spray, and mixes with it. In desiccating chambers in which the spray nozzles are installed on all sides, the heated air may enter near the bottom in the center of the desiccating chamber, pass up through and mix evenly with the spray that issues from all sides toward the center. Or the heated air may enter at the top and pass downward with the spray. Or it may enter from the sides at various points near the top, in the form of a cyclonic current moving spirally toward the center, escaping in the center through the top of the desiccating chamber. In the case of the centrifugal spray, the milk spray is usually at or near the center of the drying chamber and the heated air enters either at top or bottom.

The arrangement of the exit of the moisture-laden, spent air also differs with different drying chambers. In many cases, especially where the heated air and spray enter at one side, the exit of the moisture-laden air is on one side, in this case on the side opposite that of the intake. In other cases the spent air escapes at the top and in still others near the bottom of the desiccating chamber.

Insulation of Drying Chamber.—Since in the process of spray-drying milk the temperature in the drying room is always very much higher than that of the surrounding atmosphere, it is imperative that the walls of the drying chamber admit no air from outside. They must be tight. Leaky walls cause the cooler exterior air to enter. Peep-holes, doors and shutters must fit tightly.

The walls should be of substantial construction and as much as possible of such material and construction as to reduce loss of heat by radiation through the walls to the minimum. If lined with tin plate, as is the case in many plants, the outside is usually covered completely with asbestos sheeting. In many of the more substantial installations of recent years the walls, top and bottom are constructed of concrete or hollow tile. The interior of some of the drying chambers is lined with white glazed tile. See also Chapter II on "Metals in Dairy Equipment."

ATOMIZERS

The purpose of atomization is to insure maximum rapidity and uniformity of evaporation. The aim therefore must be maximum surface of evaporation, uniformity of particle size, and intimate mixture with the heated air. In order to accomplish this the atomizer must reduce the milk to a mist of minute particles of uniform size throughout the spray, and it must disperse the particles of this mist uniformly through the drying chamber.

For illustration of the tremendous increase in the surface of evaporation provided by atomization it may serve to state that the usual particle size of the spray is approximately 50 microns (.002 inch). One pint of milk reduced to a spray, the particles of which measure .002 inch in diameter contains 6,893,415,266 particles which present a total surface area of 300,782 square feet.

The atomizers used for this purpose are of diverse types. On the basis of principle of spray formation they are conveniently divided into three groups; namely, compressed air atomizers, pressure spray nozzles, and disc centrifugal atomizers.

Compressed Air Atomizers.—This type of atomizer appears to be the one first used in milk drying. It was a part of the original Stauf dryer and, according to Scott,[211] an atomizer of the same principle is described by Nestlé in a British patent. In the compressed air atomizer a jet of compressed air issuing horizontally from a nozzle impinges against a vertical jet of milk, dispersing the milk into a fine spray or mist.

Pressure Spray Nozzles.—This system of atomizing is used extensively in American milk drying factories. It is the atomizing spray used by Merrell-Soule, McLachlan, Gray-Jensen, and Rogers. It consists chiefly of passing the milk under high pressure (about 2,500 to 3,000 lbs.) through the fine orifice of a spray nozzle. In most of the pressure nozzles now in use the pressure is confined to pump pressure using pressure tubing of ¼ to ½ inch bore between pump and spray nozzle. Atomization may, however, be further accelerated by injection of heated air or steam under pressure.

A variety of different types of pressure nozzles are in use. The type most commonly used contains a disc of a highly wearproof, hard metal, such as hard steel alloy, stainless steel, phosphor-bronze or agate. The high velocity with which the milk under pressure of 3,000 pounds passes through the spray orifice causes rapid wear of the metal and enlargement of the orifice, hence the use of hardened metal is imperative to preserve the desired diameter of the orifice and to avoid the need of too frequent replacement. Preceding the spray disc with its orifice there is a simple contrivance that gives the milk a swirling motion before it reaches the orifice. This contrivance may consist of a small brass cylinder that fits snugly into the nozzle behind the disc. The metal cylinder has spiral grooves in its periphery. The milk passes through these grooves and thereby assumes a swirling motion at the orifice. Or the swirling device may be in the shape of a cup with slanting holes in the periphery through which the milk reaches the spray orifice in a swirling motion. The purpose of the swirling motion is to insure a wide angle of spray as it issues forth from the spray orifice.

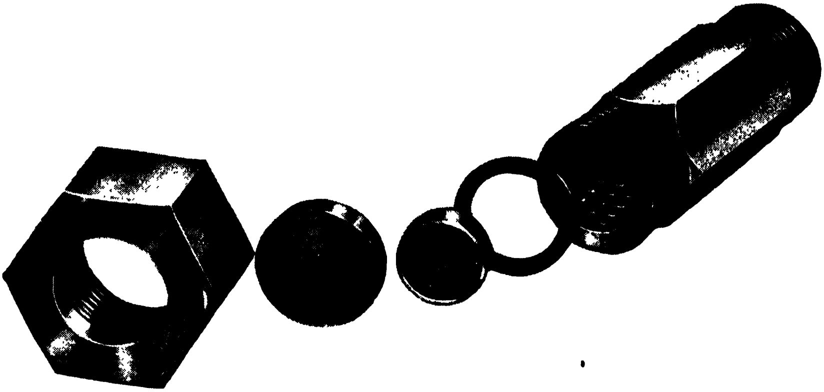


Fig. 137. The Gray-Jensen pressure spray nozzle
Courtesy of The Douthitt Corporation

The particle size of the pressure spray is approximately 50 microns (.002 inch). There is a tendency, however, for the particles at the outer edges of the cone to be larger than those of the core. The particle size is influenced by the size of the orifice, the pressure of the milk and the concentration of the milk. The larger the orifice, the lower the pressure, or the more concentrated the milk, the larger the particle size and the coarser the particles of the powder.

When spray-drying uncondensed milk which tends to produce an almost impracticably fine, fluffy powder, it is helpful to use nozzles with a somewhat larger diameter orifice than for spraying pre-condensed milk.

The small orifices through which the milk spray enters the desiccating chamber increase in size by usage due to wear; this necessitates the frequent replacing of the old caps or discs by new ones. When in operation, these spray nozzles at times become clogged and must be changed for cleaning. It is necessary, therefore, for the operator to supervise the process continually, making sure that all the spray nozzles function properly, so as to secure maximum efficiency and speed of desiccation.

Pressure Spray Pumps.—Uniform fineness of spray and maximum efficiency of desiccation demand uniform pressure of the milk. To accomplish this requires a special type of pump. Experience has shown that pumps best suited for this purpose are three-cylinder pumps with large, heavy valves and with extra deep stuffing boxes that can be packed with one-half inch packing rings, and special, heavily bolted glands that can be readily adjusted while the pump is running.

The triple cylinder arrangement insures a steady pressure and continuous flow through the spray nozzles and the deep stuffing boxes enhance the tightness of the seal. The hardening of condensed milk on the plungers is prevented by an open-pot water-seal which completely submerges the stuffing boxes, the water serving both to cool and lubricate the packing and to prevent its being hardened by absorbing condensed milk. While the pump is in operation a small stream of cold water is allowed to run into this water pot and to overflow through a suitable opening.

These pressure pumps should also be provided with proper relief or overflow valves, so as to avoid the danger of excessive pressure and variation in the spray, in case several of the spray nozzles should become clogged simultaneously.

At the finish of the run of milk, a quantity of water should be pumped through these high pressure pumps and pipes and it is advisable to allow the pumps and pipes to stand full of water when they are not in use, so as to loosen and remove remnants of condensed milk, preventing their accumulation in the cylinders and avoiding difficulties incident to plugging and clogging.

The pressure at which the milk is forced through the spray nozzles varies from 800 to 3,500 pounds per square inch, the usual range of pressure employed fluctuating between 2,000 and 3,000 pounds. The multiple nozzles with the fine openings require less pressure to secure the same atomizing effect than when using fewer or one large nozzle.

Disc Centrifugal Atomizers.—Atomizers of this type are used in the spray-drying processes of Krause, Dick and Kestner. The atomizing element consists of a horizontal saucer-shaped disc which revolves at a high velocity (5,000 to 20,000 R. P. M.), the spray being produced by centrifugal force. The disc is usually located in the center of the drying chamber. The milk reaches the surface of the disc by gravity. The centrifugal force generated by the rapidly rotating disc causes the milk to spread toward the periphery where it is thrown off in the form of a thin veil of mist-like particles which immediately assume spherical shape by virtue of the force of surface tension. The centrifugal force being proportional to the $(R. P. M.)^2 \times$ disc radius, uniformity of atomization is accomplished by adjustment of the ratio of velocity to diameter. Thus in the Krause system which aims at a particle size of .002 inch diameter, a disc of 20 inch diameter and 6,000 R. P. M. is used.

In the Krause system the disc is driven from below. The disc is hollow and the milk is fed to the center by gravity. The Krause disc does not discharge the milk over its entire periphery but through several apertures distributed at equal distances over the periphery. The disc rotates at an average peripheral speed of approximately 500 feet per second. The heated air stream enters at the bottom and rises through the atomized milk.

In the Kestner system the air current enters at the top of the chamber and passes downward through the atomized milk. The disc is bell-shaped and the milk is fed from above to the under side of the disc where it spreads evenly around the periphery and escapes from the edge in the form of a film of definite thickness. The aim here is to so control the rate of feed as to wet the entire under side of the disc and thus secure a uniform particle size.

The disc centrifugal atomizer has several advantages over the pressure spray nozzle. It has no small orifices that are subject to clogging. It, therefore, permits of the use of highly concentrated milk (as high as 50% solids), and is capable of continuous operation over prolonged periods without special attention. Its speed control offers more dependable uniformity of the particle size and it facilitates control of fineness and bulkiness of the finished product. It does not require high pressure and its cleaning is simplified.

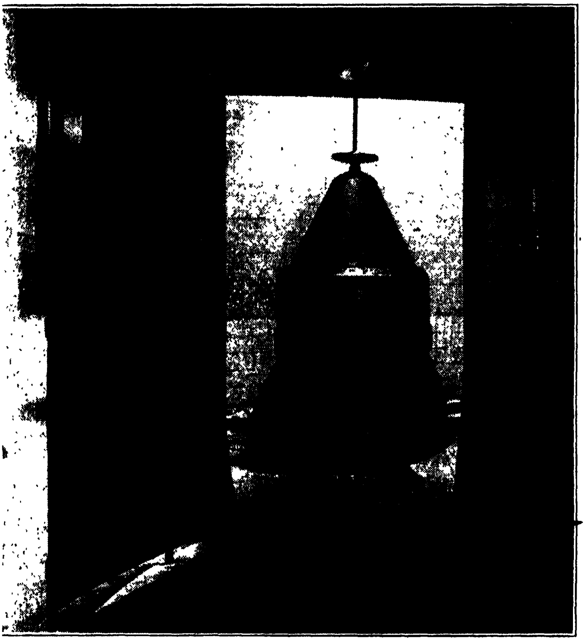


Fig. 138. The Krause centrifugal disc atomizer
Courtesy of the American Lurgi Corporation

REMOVAL AND RECOVERY OF MILK POWDER

As shown previously, the size of the milk droplets and the resulting grains of the powder vary greatly with type of spray and concentration of milk. In the case of the pressure spray nozzle they vary further with size of orifice, pressure, and different components of spray. The average size of the grains is approximately 50 microns (.002 inch) in diameter, but due to the above varying factors the grain size may range from less than 10 microns to over 100 microns. Some atomizer arrangements yield more uniform grains than others, but in each system a certain proportion of the powder represents a much finer milk dust than the remainder of the dried milk. .

Because of this range of particle size the milk particles floating in the drying chamber are subject to two principle forces. The coarser particles, which make up approximately 80 per cent or more of the total powder, respond to the force of gravity and settle to the bottom of the chamber, while the extremely small particles, the milk dust, become entrained in the air currents and follow the air stream to its exit where they are more or less completely recovered by mechanical means. Accordingly, the problem of removal of powder envolves two separate and distinct phases, namely, the removal of the coarser particles from the bottom of the chamber and the recovery of the milk dust entrained in the outgoing air.

Removal of Milk Powder from Drying Chamber.—Prolonged exposure of the dried milk to the heated air and to the hot metal walls of the drying chamber is damaging to the flavor and keeping quality of the powder. Particularly in the case of powder rich in milk fat, such as whole milk and cream powders, does high temperature jeopardize quality. When first precipitated, this dried product appears to represent an emulsion of fat in milk solids, the protein and milk sugar covering and protecting the fat against oxidizing influences of the air.

Prolonged heat exposure of the powder, on the other hand, has a tendency of reversing the phase of the emulsion. The fat melts and saturates the particles. The fat thus becomes the continuous phase. It reaches the surface of the particles, and being no longer covered and protected by the milk solids, is subject to the oxidizing action of the air. Spray-dried powder barrelled hot (without effort to cool it before packing) has been found to retain its heat for many hours. Temperature tests of barrelled milk 24 to 48 hours after packing showed as high as 135 to 145°F.

The Stauf process provides for the immediate removal of the dried milk from the heated drying chamber into hoppers where it drops away from the hot air and is discharged from the bottom of the hopper. The Milcal and Kestner processes provide for a similar arrangement of separating the powder from the direct heat of the drying chamber. The Gray-Jensen process accomplishes the same protection by continuously removing the dried milk from the bottom of the cone-shaped drying chamber by the suction of a blower fan. The Gray-Jensen patent, in addition, provides a cooling jacket for the lower part of the drying chamber. In commercial operation, however, this cooling system is not used. In the Krause system the milk powder which deposits on the bottom of the drying chamber is continuously swept onto a screw conveyor by revolving brushes. It is only in the Merrell-Soule and in the Rogers processes that the powder that accumulates on the bottom of the drying chamber remains there during operation and is removed after the day's run.

Recovery of Milk Dust.—The milk dust that is entrained in the air stream and escapes with the outgoing air is recovered wholly or in part by various means. Because of the extreme fineness of these milk particles, their terminal velocity is not sufficiently arrested by the force of gravity to cause them to drop to the bottom, and as pointed out by Scott, attempts to enlarge the air outlet to a size sufficient to accomplish precipitation by gravity would be quite impracticable.

Filter Bag Dust Collectors.—For above reasons, therefore, the reclaiming of this entrained milk dust necessitates the use of some form of dust collector. The most common type of dust collector used consists of a series of filter bags equipped with mechanical shakers. The filter bags are usually made of cotton or linen of very fine weave. They are about 6 to 10 feet high and approximately 8 to 10 inches wide.

The entire series of bags presents a large screening surface not infrequently amounting to several thousand square feet. The air is drawn through these bags, and deposits the entrained milk particles in their meshes. As the milk dust builds up on the inside of the bags they are subjected to intermittent mechanical shaking which drops the powder to the bottom of the vault in which the bags are suspended.

Supplementary Dust Collectors.—In some factories these filter bags are supplemented by preliminary recovery equipment that reclaims a portion of the entrained milk dust before the outgoing air reaches the filter bags. This equipment may consist of a progressive series of large cloth screens suspended in a vault, through which the air must pass on its journey to the filter bags. Or it may take the form of cyclone and vortex formers. These usually consist of large cylindrical containers with baffles and cone-shaped bottom. The air from the drying chamber is blown into these containers with great force, where it is subjected to a cyclonic vortex. Its impingement on the walls and baffles causes it to release and drop at least a portion of the milk particles it contains.

Because of the extremely close weave of the filter bags, their use tends to build up a slight pressure in the drying chamber, which is undesirable. The difficulty of keeping them clean and sterile is a further problem. Finally, even the closest weave is not sufficiently fine to prevent the passage of some of the milk dust, preventing complete recovery. The loss of milk solids by the use of this type of dust collector is variously quoted. In the case of drying fluid milk without pre-condensing, it may be as high as 6 to 8 per cent. With milk pre-condensed to a concentration of about 4 to 1 the loss is usually confined to approximately 2 per cent.

Electrical Dust Collectors.—Recovery by means of electrical precipitation of the entrained milk dust, by the use of such dust collectors as the Cottrell Dust Precipitator, has also been found practicable. In this system the hot air from the drying chamber passes upward through a battery of vertical metal tubes. From a high-tension bus-bar above the top of the tubes are suspended as many chains as there are tubes. These chains extend down through the center of the tubes. The bus-bar and the chains are maintained at a high voltage (according to Scott at a potential of 50,000 to 75,000 volts). The dried milk particles in the air become electrically charged and are attracted to the chain and to the tube walls, from which they are readily reclaimed. It is claimed that electrical precipitation, in the presence of sufficient voltage makes possible very satisfactory recovery of the milk. Its chief drawbacks appear to be a tendency toward a considerable increase in the moisture content of the reclaimed powder, and high initial cost of the necessary equipment and accessories.

Recovery Without Mechanical Dust Collectors.—As has been shown in the foregoing paragraphs, the recovery of the milk dust entrained in the air exhaust of the drying chamber is a real problem. Available mechanical and electrical dust collectors are capable of reclaiming the bulk of the escaping powder but they are incapable of complete recovery. In addition, they involve the installation of considerable equipment that must be operated and kept in satisfactory sanitary and mechanical condition.

The need of these dust collectors is eliminated and practically 100 per cent recovery accomplished where the air leaving the drying chamber is passed through a spray of the incoming fluid milk as is the case in the Gray-Jensen process explained earlier in this chapter. By this means the entrained milk particles are completely absorbed by the fluid milk, increasing its solids content. This process has the further advantage of thus utilizing the heat and incomplete saturation of the hot air for precondensing the fluid milk.

PREPARATION FOR MARKET

Grinding, Bolting and Sifting.—The milk powder made by spray-drying requires no grinding. It is of a fine, floury grain, and after bolting and sifting it is ready to be packed in bulk or in the consumer package. The film-dried milk comes from the drying drum in crinkly sheets and shreds, which break up into a relatively coarse and uneven size grain in the conveyor. This material is ground to a fine powder, bolted and sifted.

Cooling the Powder.—As previously shown, prolonged exposure of the dried milk to high temperature jeopardizes its flavor and keeping quality. This danger is particularly pronounced in the case of powders rich in milk fat. It was also pointed out that, if the powder is packed while hot it will retain its heat in bulk packages, such as barrels, for several days. It is important, therefore, that conditions be provided that insure a reasonably low temperature (room temperature) of the powder when packed.

Atmospheric drum-dried milk usually is cool by the time it reaches the package because of its quick and complete removal from the drying heat and the cooling effect of the atmosphere. Vacuum drum-dried powder, likewise, surrenders its heat readily between dryer and package. Spray-dried powder presents a somewhat different situation. Whether it remains in the hot drying chamber until the end of the day's run, or is continuously removed, if packed immediately and without special provisions for cooling, the tendency is for it to be packed hot and, in the case of the bulk package (the barrel), this heat is retained for a considerable time. This may best be avoided by providing a practical system of cooling after leaving the drying chamber. In the case of the Gray-Jensen process this problem has recently been solved by admitting refrigerated air into the powder as it is drawn through the Ramshorn pump.*

Packing the Dried Milk.—The dried milk is packed into containers of various types and sizes. The container should be air-tight and moisture-proof, to protect the goods from the oxidizing action of the air and from absorption of moisture in the case of humid air, which impairs its solubility and invites the development of staleness and other flavor defects.

The usual bulk package is the barrel which should be coated on the inside with an impervious layer of paraffin, sodium silicate or casein preparation. The barrel is lined with a suitable paper lining. The average net weight of the barrel is 250 pounds, the exact weight depending on the bulkiness of the powder, and this in turn is controlled by the process of drying used. As previously explained, the coarser grained product of the dough-drying and film-drying system is heavier and less bulky than the finer and more porous grain of the spray-dried powder. Of the latter, that which is made from uncondensed milk is more bulky and lighter than the powder made from highly pre-condensed milk.

The great bulk of the skimmilk powder output reaches the market in barrels. Of the smaller packages, the sizes range from 8 ounces to 25 pounds. The type of these packages varies and embraces fibre containers, tins, and glass jars. The 10 pound tin with friction top predominates. The glass jars with hermetical seal are preferred for whole milk powders and cream powders. They generally serve for packing in vacuum or in an atmosphere of an inert gas such as nitrogen. These packages usually hold from one pound to five pounds of the powder.

Storage.—The most suitable storage temperature is ordinary cooler temperature (35 to 45°F.). It is at this temperature range at which the dried milk is best protected against age-deterioration as far as such deterioration is controlled by storage temperature. In the case of milk powder packed under vacuum or in an atmosphere of nitrogen, or other suitable inert gas, the temperature of storage is less important. The principle deteriorating agency is the air. The damaging action is intensified by high temperature. Absence of air diminishes and largely eliminates the possibility of damage by heat. The fundamental purpose of vacuum- or nitrogen-packing, in fact, is to be able to place the goods on the shelves in the store where they are subject to a wide range of temperatures, without danger of rapid age-deterioration under unfavorable temperature conditions.

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*This improvement was originally suggested by Mr. Paulson, President of the Dried Milk Corporation of America, Chicago, Illinois.

YIELD OF MILK POWDER

The approximate yield of milk powder per 100 pounds of fluid product is given below:

Whole milk powder	11.5	to	14.5	lbs.
Skimmilk powder	8.5	to	9.5	lbs.
Buttermilk powder	7.75	to	8.75	lbs.
Whey powder	5.5	to	6.25	lbs.
Cream powder	30	to	55	lbs.

The dominating factors that influence or control the yield of dried milk are: composition of fluid milk product, efficiency of recovery and moisture content of finished product.

The composition of the fluid milk (per cent total solids in whole milk and per cent solids not fat in skimmilk) is controlled chiefly by breed and period of lactation. It varies, therefore, with locality and season of year. The per cent total solids and solids not fat as affected by breed has been found to average approximately as follows:

Breed	Total solids in whole milk Percent	Solids not fat in skimmilk Percent
Jerseys	14.51	9.36
Shorthorns	12.85	9.01
Ayrshires	12.63	8.71
Holsteins	11.84	8.56

The variations of solids not fat for all breeds during 56 consecutive weeks of the period of lactation, in fourteen 4-week periods, are graphically illustrated in Fig. 139.

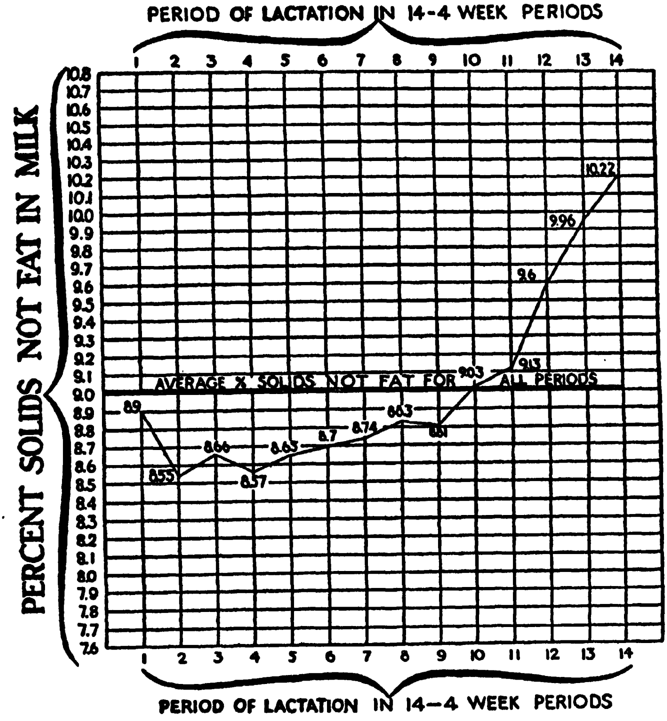

Fig. 139. Effect of period of lactation on per cent solids not fat. Averages of all breeds

In the case of dried buttermilk the yield is materially affected by the extent of dilution which the cream has suffered through inevitable additions of water in rinsing cans and factory equipment prior to churning.

In the case of cream the dominating factor is the per cent of fat in the original cream. The recovery of cream solids is generally somewhat less complete than with the whole milk or skimmilk and the low moisture content (below 1%) tends to further depress the yield.

CHAPTER XXXI.

COMPOSITION AND PROPERTIES OF MILK POWDERS

Chemical Composition of Milk Powders.—The chemical composition of milk powders varies principally with the percentage composition of the original milk from which the powder is made, and to some extent with the process of desiccating.

The percentage composition of the fluid milk, aside from skimming or the addition of milk fat, is controlled primarily by locality and season of year, as determined by breed, period of lactation and feed of the cows. For these reasons milk powders made by the same process, but in different localities and at different seasons of the year, often show considerable variations in their pecentage composition.

The process of drying affects the percentage composition of the dried product largely from the standpoint of its moisture content only. Some milk powders also contain added sucrose. Alterations in the nature of the milk constituents such as may occur as the result of the process of manufacture, especially under abnormal temperature conditions, are generally not of a character that involves loss of milk solids components, mechanically or due to other causes, that would change the percentage composition. Slight fat losses may, however, occur due to fat melting during drying when high-fat powder is caused to come in contact with high temperature metal surfaces.

Effect of Process of Drying on Moisture Content.—The moisture content of the powder varies considerably with system of drying and may also differ to a lesser extent between processes of the same system. It is affected also by the fat content of the milk and by the degree of atmospheric humidity at the time of manufacture.

Powders of the dough-drying and film-drying systems usually show a somewhat higher moisture content (about 3.5% to 8% moisture) than spray-dried powders (about 1% to 3.5% moisture). Cream powders contain less moisture (about .35% to .08%) than dried whole milk and dried skimmilk. When the

Table 44.—Moisture Content of Spray-Dried and Film-Dried Milk.

	Spray-Drying Process			Film-Drying Process		
	Percent	Percent	Percent	Percent	Percent	Percent
Water	1.70	3.14	2.12	3.95	7.70	5.46
Total Solids	98.30	96.86	97.88	96.05	92.30	94.54

Table 45.—Chemical Composition of Milk Powders.

Analyses Made or Reported by	Water %	Butter-fat %	Pro-tein %	Milk Sugar %	Ash %	Cane Sugar %
Whole Milk Powders:						
Richmond*	6.39	27.35	27.48	31.42	6.00	....
Richmond*	4.92	27.98	24.59	34.16	6.24	1.25
Richmond*	4.74	29.16	26.66	32.24	5.63	....
C. Huyge†	3.62	26.75	32.06	31.90	5.67	....
Larsen & White‡	1.40	29.20	26.92	36.48	6.00	....
Otakar Laxa§	4.07	25.00	24.84	35.75	6.20	3.13a
Merrell-Soule Co.**	1.50	28.20	26.67	37.88	5.75	....
Part Skim Milk Powders:						
Richmond*	5.15	19.90	31.10	34.96	7.11	....
C. Huyge†	5.01	15.26	38.39	34.67	6.67	....
C. Huyge†	8.30	13.00	30.57	48.85	7.28	....
Larsen & White‡	5.00	15.12	33.30	39.70	6.90	....
Otakar Laxa§	5.46	21.96	25.69	40.93	5.74	1.16a
Otakar Laxa§	4.80	17.13	29.88	40.72	6.84	5.08a
Otakar Laxa§	5.85	15.72	30.95	40.67	6.06	1.46a
Merrell-Soule Co.**	2.12	14.20	32.26	44.41	7.01	....
Skim Milk Powders:						
Richmond*	3.55	2.55	35.45	45.60	7.89	2.80
C. Huyge†	7.40	1.00	37.28	46.30	8.00	....
Larsen & White‡	7.00	1.00	37.00	47.00	8.00	....
Otakar Laxa§	7.15	1.57	33.29	47.23	8.03	....
Stocking**	2.40	1.35	37.70	49.94	8.21	....
Mojonnier Bros. Co.¶	3.39	1.25	33.94	50.88	7.87	....
Mojonnier Bros. Co.¶	1.72	1.15	35.01	52.24	8.03	....
Mojonnier Bros. Co.¶	1.00	1.97	34.75	51.92	8.24	....
Cream Powders:						
Merrell-Soule Co.**	.80	50.40	19.19	25.45	4.16	....
Merrell-Soule Co.**	.66	65.15	13.42	17.86	2.91	....
Merrell-Soule Co.**	.56	71.15	11.12	14.74	2.43	....

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* Richmond, Dairy Chemistry, 1914.

† C. Huyge. La Poudre du lait, Revue générale du lait. Vol. 3, No. 14, 1904. Also Leach Food Analyses.

‡ Larsen & White. Dairy Technology, 1913.

§ Otakar Laxa. Berichte der laktologischen Anstalt der k. k. böhmischen technischen Hochschule in Prag. Vol. VIII, 1917.

** Merrell-Soule Co. Descriptive Bulletin Concerning Merrell-Soule Powdered Milk, 1918; also Stocking, Manual of Milk Products, 1919.

¶ Mojonnier Bros. Co. Anaysis by request of author, 1919.

a Hydrocarbons in ash.

atmospheric humidity is high, conditions for the production of low-moisture powder are less favorable than on days of low atmospheric humidity.

Milk powder has pronounced hygroscopic properties. It takes up moisture readily from the surrounding air. All milk powders will increase in moisture content with age, unless sealed in moisture-proof, air-tight containers. For dependable and comparable determinations of the performance of any given process or system of drying, the powder should be analyzed immediately upon removal from the drying chamber. The moisture content of dried milk has a marked effect on the solubility and keeping quality of the powder, as explained later in this chapter and in Chapter XXXII.

The analyses in Table 44 are fairly representative of the relative moisture content of spray-dried and film-dried milk. In Table 45 are assembled values of composition of diverse milk powders compiled from the results of analyses by various authors.

SOLUBILITY OF MILK POWDERS

The market value of dried milk is materially affected by the solubility of the product. Solubility is an important factor, especially in the manufacture of reconstituted milk that is to take the place of the fluid milk supply at the table of the consumer. It is important also in case of certain industrial uses, such as for starter making, etc.

The term "solubility" is here used in a sense sufficiently broad to be applicable to liquids of so complex a physical nature as is the case with milk. Milk is not a true solution. It is an emulsion in which some of the constituents, such as the lactose, albumin, and part of the mineral salts, are present in solution. In this solution are suspended in a very finely divided state such other constituents as the fat, the casein and the remainder of the ash. A soluble milk powder here implies a product that is capable, when mixed with water in proportion resembling the percentage composition of normal fluid milk, of returning to a solution, suspension and emulsion that will simulate the physical characteristics of natural milk. It means suspension stability, rather than true molecular solubility.

The solubility of milk powder varies with the quality and acidity of the fresh milk, the process of manufacture and the conditions of its operation, the moisture content, age and conditions of storage of the finished product. These factors affect the solubility chiefly to the extent to which they alter the physical properties and behavior of the proteins of milk, the chief of which are the casein and the albumin. Their effect on the mineral salts is also a factor though apparently of lesser prominence, in determining the solubility of the finished product. Earlier processes prescribed the admixture to the milk of alkalies in order to preserve the solubility of the proteids, which otherwise were rendered insoluble by the high heat of the respective processes. Powders so made invariably are inferior in quality to those made without admixture of chemical neutralizers. The manufacture of high grade milk powder for human consumption does not permit of the use of alkali. The problem of preserving the solubility through proper control of manufacture, therefore, is of economic importance.

Effect of Quality of Fresh Milk on Solubility.—The manufacture of milk powder of high solubility requires milk that is fresh and has not undergone any fermentation changes. The presence of developed acidity, or acidity additional to that contained in the milk when first drawn, and which additional acid is due to bacterial fermentation, diminishes the solubility of the milk powder. This is in all probability due to the well known action of lactic acid on the calcium-casein combination as explained in Chapter XV on "Heat Coagulation." The action of the acid is intensified in the case of milk powder by the high concentration of the product and by the heat of desiccation. High-acid milk taken in at the receiving platform, continues to develop acidity rapidly, as pointed out by Fleming and Nair,[82] and this further augments the damaging effect on the solubility of the finished product.

Fresh milk otherwise of poor quality, such as milk contaminated with rennin-forming bacteria, also jeopardizes the solubility of the milk powder, because these rennet-like enzymes act on the casein and tend to render it insoluble as explained in Chapters III and XV.

Effect of Process of Manufacture on Solubility.—The process of manufacture influences the solubility of the milk powder chiefly in so far as the heat exposure in pre-heating or pre-condensing, in drying and before removal from the drying heat, alters the physical properties of the proteins and the mineral salts. The chief factors involved are temperature and time of exposure and concentration of the milk. The results of solubility tests by the author, tabulated in Table 46 may serve to give a general idea of the comparative solubility of powders made by the atmospheric and vacuum drum dryer and by the spray-drying system.

Table 46.—Solubility of Milk Powders of Film-Drying Process, and of Spray-Drying Process.

Process of Desiccation	In Cold Water 78.5° F.		In Hot Water 210° F.	
	Percent in Solution	Percent of Powder Dissolved	Percent in Solution	Percent of Powder Dissolved
	Total Solids			
Film-Process Powders:				
Skim milk powder (atmospheric)..	3.94	69.61	4.42	78.09
Cream powder (atmospheric).....	3.46	61.13	4.53	80.03
Skim milk powder (vacuum).....	....	....	5.49	97.00
Spray-Process Powders:				
Skim milk powder (milk heated to 150° F. before desiccation).....	5.61	99.12	5.76	101.76
Skim milk powder (milk heated to 210° F. before desiccation).....	5.09	88.16	5.33	94.17
	Protein			
Film-Process Powders:				
Skim milk powder...............	.41	....	.65	....
Cream powder...................	.49	....	1.62	....
Spray-Process Powders:				
Skim milk powder (milk heated to 150° F. before desiccation).....	2.00	....	1.97	....
Skim milk powder (milk heated to 210° F. before desiccation).....	1.47	....	1.74	....

Table 46 shows that the spray-dried powder made from milk pre-heated to 150°F was substantially completely soluable in cold water. The same powder made from milk pre-heated to 210°F lost slightly over 10 per cent of its solubility. About one-half of this loss was recovered when dissolved in water heated to 210°F.

The atmospheric film process powder, when dissolved in cold water, went into a filterable emulsion to the extent of 60 to 70 per cent of the powder added; and in hot water to the extent of 78 to 80 per cent. The powder of the vacuum film-drying process showed considerably higher solubility. In hot water 97 per cent went into solution.

The very marked difference in solubility of the powders from the two processes could be readily observed also without chemical analysis. When the solutions of the film-process powders were allowed to remain at rest in test tubes there would always gather a very considerable deposit of solid matter in the bottom. This was the case in both hot and cold water, but the deposit was considerably more voluminous in the cold mixture than in the hot mixture. In the case of the spray-process powders, made from milk forewarmed to 150°F. or below, no such deposit of solid matter could be detected, either in the hot or in the cold mixtures.

It is further interesting to note that the percentage of protein found in the filtrates from all the powders, with the exception of the hot solution from the film process cream powder, followed very closely the percentage of total solids in the same filtrates. This clearly suggests that the degree to which the solubility of the milk powder is impaired by the process of desiccation, is largely controlled by and depends on the extent to which the process changes the properties of the proteins of milk.

Solubility of Film-Dried Powders.—The relatively low solubility of milk dried on atmospheric drum dryers is a fact established both experimentally and by practical experience over a period of years. It has been experimentally shown further that the chief constituents involved in the insoluble matter of reconstituted drum-dried milk are proteins and mineral salts.

Supplee and Bellis[213] found that, in powder made by the Just-Hatmaker process (atmospheric film-drying), the material precipitated by centrifugal force from reconstituted milk contained approximately 93 per cent protein material and 7 per cent ash. The ash was almost entirely composed of oxides of calcium, magnesium, and phosphorus. They concluded from their analysis that insoluble calcium phosphate is the principal constituent of the precipitated mineral matter.

Wright,[214] in the most comprehensive investigation on record on this subject, studied the temperature-time-concentration factor in its relation to the actual conditions that may prevail from the time the liquid film of milk is first deposited on the revolving roll until the dried film reaches the scraper. He holds that, in its journey from fluid milk trough to scraper, the milk film passes through three important phases; the first phase representing that stage of evaporation when the milk is still in liquid condition, the concentration of milk solids is still low, the high rate of evaporation depresses the temperature and overheating with consequent denaturation of the protein, therefore, appears unlikely; the second phase, which coincides with the formation of a viscous film containing a high percentage of milk solids and which may be expected to constitute the critical period of heat treatment; and the third phase, when the milk film has reached the dry stage.

Effect of Time-Temperature-Concentration Relationship on Solubility.—Experiments by Wright in which milk of various concentrations of milk solids was exposed to different temperature-time relationships showed the following results:

1. For a given temperature, the higher the concentration of milk solids, the more easily is the protein rendered insoluble.

2. For a given time of heating, an increase of 1 per cent in the concentration of solids lowers the temperature required to produce a given degree of insolubility by about 1°C. (1.8°F.).

Thus, with solutions containing less than 20 per cent solids, heating at 100°C. had no effect on solubility. With solutions containing 35 per cent solids, over 75 per cent of the protein was rendered insoluble. Further work showed that to render 50 per cent of the proteins insoluble required the following temperature-time-concentration ratios:

10 min. at 100°C. required a solids concentration of 28%.
10 min. at 95°C. required a solids concentration of 33%.
10 min. at 90°C. required a solids concentration of 38%.

3. At temperatures approximating 100°C. (212°F.) insolubility in the lower concentrations was induced only after fairly prolonged heating, while in solids concentrations between 60 and 90 per cent, insolubility may be induced by heating for periods varying from a few seconds to a fraction of a second.

By expressing the temperature-time-concentration relationship logarithmically and by extrapolation of the logarithmic curve, Wright obtained theoretical values of temperature-time relationships that approximate more nearly the temperatures incident to actual operation of the atmospheric drum dryer. Accordingly, with a solids concentration of 86.66 per cent, for instance, the approximate time required to induce 50 per cent protein insolubility was 6/10 second at 100°C., 1/10 second at 110°C., 3/100 second at 120°C., and 7/1000 seconds at 130°C.

4. Overheating the milk in the dry state increased the insolubility, the rate of production of insolubility being directly proportional to the time of heating, and the velocity of the reaction increasing greatly with increasing temperature. Fifty per cent insolubility of the casein was produced in the presence of the following temperature-time ratios:

At 100°C. in 10 hours.
At 117°C. in 35 minutes.
At 123°C. in 10 minutes.
At 129°C. in 3 minutes.
At 139°C. in 40 seconds.

5. Extrapolation of the logarithmic curve for the actual temperature-time relationships shown in the above figures, yielded the following theoretical values of approximate time required to induce 50 per cent insolubility of the casein as the result of heating in the dry state to temperatures above 139°C.:

145°C. in 10 seconds.
150°C. in 7 seconds.
155°C. in 4 seconds.
160°C. in 1 second.
165°C. in 5/10 second.
170°C. in 2/10 second.

Effect of Heat Treatment of Wet and Dry Film on Solubility.—The available data of solubility tests with milk of various concentrations and with dry milk, and their theoretical deductions suggest that in practice the solubility-destroying action is most intense in that portion of the drying milk film of the revolving drum which has reached a high concentration of solids and before it has attained the dry stage. It is conceivable, on the basis of Wright's results and calculations, that solubility-decreasing overheating of the dried film may occur also, particularly in the presence of a thin film that reaches the dry phase early, and when extremely high drum temperatures are used.

Low Solubility of Powder from Atmospheric Drum Dryer.—In view of the above findings, and because of the fact that in atmospheric drum-drying as represented by the Just-Hatmaker type of process the temperatures employed approximate 130 to 140°C. (266 to 284°F.) or even higher, and that during a portion of its journey from milk trough to scraper the still wet milk film represents a high concentration of solids, a relatively low solubility of the powder produced by this process appears inevitable. As previously stated, this is in fact the usual commercial experience with Just-Hatmaker powder.

In the case of atmospheric drum drying processes of the type of Mignot-Plumey, Gabler-Saliter, and Kunick, however, which are claimed to employ much lower drying temperatures (92 to 95°C.), it appears reasonable to assume that the resulting powder is considerably more soluble.

Still another situation of heat exposure in film-drying occurs in the case of drum dryers of the Passburg, Ekenberg and Buflovak type of machines. Here the temperature of the drying chamber in which the drums operate is lowered far below the boiling point by the reduced pressure, the drying being done in a high vacuum. Moreover, in the Buflovak Vacuum Drum Dryer the temperature of the drum heating surface is held below the boiling point by maintaining a partial vacuum in the steam-heated drum. While exact information is lacking regarding the effect of the heat application in these machines on the casein, solubility tests show that the resulting milk powder is considerably more soluble than that from atmospheric drum dryers of the Just-Hatmaker type.

Reactions Responsible for Insolubility of Drum-Dried Powder.—Regarding the exact reactions involved in the destruction of solubility, observations suggest that the increase of insolubility of the wet milk film on the atmospheric drum is fundamentally a heat coagulation problem. Similarly as in the case of heat coagulation in evaporated milk, the factors responsible appear to deal with balance of particle charge, or more explicitly, calcium-casein balance, the heat precipitating calcium phosphate, thus disturbing the calcium-casein balance and impairing the stability of the casein, as explained in Chapters XV and XXIII.

In the case of the effect of overheating the milk in the dry state, the chief action appears to be one of intensive casein-dehydration, such as the removal of water of imbibition from the casein particle which, according to Wright, may explain the phenomenon of differential solubility (more soluble in hot water than in cold) which is a usual characteristic of milk powder of the atmospheric drum drying system.

Solubility of Spray-Dried Powders.—The spray-drying system yields a milk powder of greater solubility than the film drying system. In fact, spray-dried powders are practically completely soluble when fresh and when manufactured under proper and now well understood temperature conditions. This is true of the product from both the pressure and the centrifugal spray-drying processes.

In spray-drying the milk solids do not come in intimate contact with the high heat employed. They are not exposed to high-temperature metal heating surfaces, such as the steam-heated drying drums used in the film-drying system. While the temperature of the air currents entering the drying chamber is not unlike that of the drying drums, ranging from about 120 to 150°C. (248 to 302°F.), and averaging about 127°C. (260°F.), it appears that the milk solids do not actually come in contact with such high temperatures.

In spray-drying dehydration is extremely rapid, almost instantaneous, and this great velocity of evaporation has a cooling effect on the particles of the milk. As explained in Chapter XXX, the rapidity of evaporation in the spray process is caused by two factors. One of these is the greatly enlarged surface area of the milk due to the minuteness of the spray particles. The other has to do with the velocity with which these small milk particles travel, causing them to rapidly pass from strata of heated air of high humidity to strata of heated air with lower humidity.

High Velocity of Evaporation in Spray-Drying.—This phenomenon of rapidity of evaporation and its effect on the solubility has been admirably described by Philippe[219] from the standpoint of the Krause process (centrifugal spray). Because of the tremendous speed of the Krause spray disc, both the surface area due to most minute division, and the velocity of the milk particles are very great. Evaporation of a large portion of the moisture contained in the milk spray is, therefore so rapid, that the milk particles are not given sufficient time to absorb the heat necessary for evaporation from the heated air. They are forced to utilize and give off their own heat and thereby cause a reduction in temperature. This cooling effect of the liquid is inevitable because the heat loss due to evaporation is greater than the heat received by convection from the air. Hence the removal of the great bulk of the moisture, or the main portion of the drying process, takes place at a relatively low temperature. This is important because it is at the point, when the particles are in liquid condition, that the proteins are most sensitive to the action of heat, and when exposure to high temperature would cause marked changes that depreciate the solubility of the finished product. Following Philippe's logical reasoning then, theoretically the milk particles, so long as they still contain moisture, are cooled rather than heated in the presence of the heated air.

Cooling Effect in Spray-Drying.—Theoretical calculations indicate the following temperature conditions in the drying chamber of the Krause process. It is assumed, for the purpose of this example, that the air entering the heating vault has a temperature of 20°C. (68°F.), contains 50 per cent humidity and is heated to 150°C. (302°F.). The heated air, when taking up enough moisture from the milk spray in the drying chamber to become completely saturated, is thus cooled off. In this example the saturation point would be reached at 41°C. (105.8°F.). The spray particles under these conditions, and as long as they still contain traces of moisture, could, therefore, not attain a temperature higher than 41°C. (105.8°F.).

Time-Reaction Negligible in Spray-Drying.—This is important from the standpoint of preserving the solubility as well as other desirable characteristics, such as flavor, odor, and color. It is well known that the disturbing influence of heat on the sensitive equilibrium of colloidal products, such as milk, requires a certain time to materialize. The action of heat here is a time-reaction. In the spray-drying the dehydration is so rapid, consuming only a small fraction of a second, that these time reactions are practically impossible. On the other hand, as Philippe points out, when the drying process is once completed, the dried product becomes more or less immune to the action of heat. In a low-moisture condition even colloidal substances highly sensitive to heat, such as proteins, ferments and sera are only slightly, if at all, affected by high temperatures, such as are employed in the form of heated air in the spray-drying process.

In the pressure spray-drying processes the fineness of division and the velocity of spray particles are similar to those in the Krause system. While there may occur marked differences in intensity of these factors in the operation of specific processes, in general the results are not dissimilar, and evaporation is exceedingly rapid. These facts and theories, then, indicate that the solubility of the finished product resulting from the spray-drying system, when properly operated, is not impaired, and solubility tests fully support these conclusions.

However, the production of a perfectly soluble milk powder, even by spray-drying, is possible only provided that the milk, before it enters the drying chamber, has not been subjected to sufficiently high temperatures to seriously affect the physical properties of the protein constituents. This means that the preheating and condensing, in the case of pre-condensed milk, must be done at temperatures considerably below the boiling point. The use of high forewarming temperatures, such as 180°F. or above, very materially lowers the solubility of the resulting powder.

Effect of Overheating of Dry Spray Powder.—The danger of diminishing the solubility of spray-dried powder by overheating in the dry state apparently is not great. To be sure, when dry, evaporation ceases and there is no longer any cooling effect. Powders left in the drying chamber will rapidly heat to the temperature of the metal walls and the air of the drying chamber. In the case of very high temperature of the incoming air and prolonged holding of the powder in the drying chamber, it is possible that solubility might be sacrificed. The risk of damaging the solubility due to such overheating, however, appears to be negligible. Commercial experience in the manufacture of spray-dried milk by processes which retain the dry powder in the hot drying chamber until the end of the day's operation shows that these powders are still completely soluble. But in the case of whole milk and cream powders, such long heat exposures of the dried powder have a damaging effect on flavor, as will be shown in later paragraphs.

Effect of Moisture Content and Storage Temperature on Solubility of Milk Powders.—The solubility of milk powder diminishes with age. This change increases with an increase in moisture content and with a rise in storage temperature. The decrease in solubility due to high moisture occurs regardless of whether the excessive moisture is present in the fresh powder or has been absorbed subsequently from the atmosphere. The solubility-damaging effect of high moisture occurs in both spray-process and film-process powders.

Insolubility of High Moisture Powder.—Supplee and Bellis,[218] made a comprehensive study of this subject, treating different lots of milk powder with moist and dry air, respectively. They were able to increase the per cent moisture in dried milk from 2 to 11 per cent by circulating moist air of a humidity of 70 to 75 per cent through the powder. The protein in milk powder treated with moist air became almost entirely insoluble, while treatment with moisture-free air caused it to retain its original solubility or emusifying power completely and they believe that complete exclusion of air would preserve the solubility indefinitely.

Similar observations concerning the relation of moisture in milk powder to its solubility are reported by Fonassieu[220] who reports that a milk powder containing only 1.6 per cent of moisture retained its solubility much longer than one containing 6.82 per cent moisture. He holds that this is because the presence of moisture increases the rate at which the lactic acid renders the casein insoluble.

Optimum Moisture Content for Maximum Insolubility.—Wright points out the impossibility of obtaining any indication of the influence of moisture content on the velocity of the reaction at any given temperature by methods in which the increase of moisture is effected by passing moist air over layers of milk powder. He holds that such measures of the increase in moisture content and decrease in solubility are impaired by the constantly increasing moisture content. He therefore emphasizes the importance of the findings of Lampitt and Bushill,[286] who conducted an investigation in which the concentration of solids was kept approximately constant for each series of experiments. Their results revealed that under such controlled conditions there exists an optimum concentration of moisture at which the increase of insolubility proceeded at a maximum rate. They found this optimum concentration to lie between 12 and 13 per cent moisture.

Effect of Storage Temperature on Solubility.—The curve established by Wright, which was referred to earlier in this discussion, gives the time-temperature relationship that will induce 50 per cent protein insolubility in milk with a moisture concentration approximating the optimum moisture content found by Lampitt and Bushill (Wright used a moisture concentration of 13.34%). In this curve the experimental points for all temperatures, including those of storage as well as those of heat treatment in manufacture, fall on a straight line. This fact strongly suggests that the reaction that takes place at storage temperatures is identical with that which takes place during the heat treatment of the drying process.

Reducing Wright's curve to figure values, his results show the following approximate time-temperature relationships for milk powder containing 13.34 per cent moisture and stored at temperatures ranging from 32 to 91.4°F.:

At 0°C. (32°F.) 50% insolubility was induced in 9¼ days.

At 18°C. (64.4°F.) 50% insolubility was induced in 27¾ hours.

At 33°C. (91.4°F.) 50% insolubility was induced in 2¾ hours.

Causes of Age-Insolubility of Milk Powder.—On the basis of available data, therefore, it appears reasonable to conclude that the progressive insolubility that milk powder suffers in storage is not due to the action of the air as such, nor to bacterial activity, but has to do with physico-chemical changes of the protein (chiefly the casein) in the presence of moisture; that an increase in moisture content increases the velocity of the reaction, the insolubility developing much more rapidly in moist powders than in dry powders; and that moist powders become insoluble more rapidly as the storage temperature is raised. For the practical prevention of age-insolubility, therefore, emphasis must be placed on low initial moisture content, protection against contact with humid air by packing the powder immediately after manufacture into air-tight and moisture-proof containers, and reasonably low storage temperatures.

Miscibility and Readiness of Solution of Milk Powders.—The rapidity and readiness with which milk powders go into so-called solution does not always depend on their actual solubility, but may be materially influenced by the size and character of the powder grain.

The spray-process powders usually are of a finer particle-size and the grains are more fluffy because of their porosity, than the drum powders which present a somewhat coarser and more granular character. These differences in size and character of grain suggest that the spray powder offers a large surface of contact with the solvent and should therefore go in solution more rapidly than the latter. This is actually the case within certain limits.

Effect of "Caking" on Miscibility.—Beyond a certain point of fineness and fluffiness, however, mechanical handicaps enter into the problem, that tend to retard solution, at least in the beginning. In the case of excessively fine and fluffy powders, the exposed area of contact is so great that there is an increased tendency toward running and lumping together, forming a pasty coating around the remainder of the particles within. This coating hinders and retards the penetration of the powder by sufficient water to complete the solution, thus retarding complete solution, at least at the start. The solution-retarding "caking" phenomenon is further augmented by the extreme lightness of these fluffy grains, causing them to float on the surface and to become hydrated by imbibition.

The fineness of the spray powder is controlled principally by size of spray nozzle orifice, pressure of milk and concentration. The smaller the orifice, or the greater the pressure, or the lower the concentration of the milk, the smaller the particle size and the more porous and fluffy the texture. Spraying without pre-condensing, other factors being equal, produces a much finer and more fluffy powder which shows a greater tendency to objectionable "caking" than powder made from pre-condensed milk. The higher the concentration the coarser and less porous the powder.

According to Troy and Sharp[290] the caking of dried milk is due chiefly to the action of the milk sugar which they believe, is present in the dried milk in the form of a very concentrated syrup. This concentrated lactose syrup absorbs moisture, facilitating adherence of the milk particles to one another; this action is accompanied or followed by crystallization of some of the lactose as alpha hydrate, causing solidification of the mass.

Miscibility of Dried Whole Milk and Dried Cream.—Ease of solution in the case of whole milk and cream powders may be impaired further by the state of dispersion of the butter fat. Without homogenization before drying, the fat globules are not sufficiently dispersed to prevent bothersome oiling-off or churning during the operation of reconstituting. When pre-condensing to a concentration of 4 to 1 or greater, spray-drying has a marked homogenizing effect which is generally sufficient to prevent churning and oiling-off trouble. At much lower concentrations, that is, when pre-condensing is not carried so far, or in the absence of any pre-condensing, spray-drying does not accomplish sufficient homogenizing action and the use of the homogenizer at 2,500 to 3,000 pounds pressure is necessary to avoid churning and oiling-off upon reconstitution. The desired homogenizing effect may also be accomplished by materially increasing the pressure of the milk when using the pressure spray nozzle.

Cream powder is usually made from uncondensed cream, hence it must be homogenized before drying. The drum-drying principle does not provide any homogenizing action, hence fat trouble, when reconstituting drum-dried whole milk powder or cream powder, can be avoided only by homogenization before drum-drying.

BACTERIOLOGY OF MILK POWDERS

When properly manufactured and stored, milk powders are not subject to deterioration of bacteriological nature. The moisture content of normal milk powder is far below the requirements for microbic activity, a fact which precludes the possibility of the development of micro-organisms usually encountered in milk. Because of this fact bacteriological analyses of milk powders made by numerous investigators have invariably shown that there is no increase in bacteria after the dried milk has been sealed in the final package, and that the micro-organisms originally present actually decrease with the age of the powder. This is the case with all milk powders regardless of process of manufacture.

Number of Bacteria in Milk Powders.—Judging from available bacteriological analysis it appears evident that all milk powders contain micro-organisms of diverse species. The presence of bacteria in dried milk is attributable in part to the ability of some species to survive the temperatures of desiccation and in part to recontamination after drying. The drum-dried powders usually show a lower bacterial count than the spray-dried powders. This is in harmony with our knowledge of the temperatures and time of exposure of the two processes, as discussed in previous chapters. The relative number of bacteria found in powders of the atmospheric drum-dryer and the spray-process are shown in Table 47.

Table 47.—Bacterial Counts of Spray-Dried and Drum-Dried Milk Powders.

Analyst	Source of Powder	Bacteria per Gram
	Spray-Dried	
Delepine (221)	Powder direct from drying chambers	10,000 to 15,200
Downs (222)	Made from pre-condensed milk	15,600 to 595,000
Downs (222)	Same process but not condensed	1,500,000 to 3,500,000
Tillmans & Strohecker (223)	Krause process	5,000 to 30,000
Macy (224)	Domestic brands	4,400 to 5,500,000
Macy (224)	Foreign brands	5,400 to 3,100,000
	Drum-Dried	
Delepine (221)	Just - Hatmaker process, direct from drums	70 to 300
Delepine (221)	Same after powdering	5,940 to 14,600
Downs (222)	Modified Kunick process	16,900 to 626,000
Grosso (225)	Just-Hatmaker process	4,000 to 5,400
Hoffman (226)	Just - Hatmaker process, whole milk	4,000 to 5,000
Hoffman (226)	Just - Hatmaker process, skimmilk	2,200 to 6,000
Hueppe (227)	Just-Hatmaker process	800 to 6,400
Kossowicz (228)	Just - Hatmaker process, direct from drums	45 to 80
Kossowicz (228)	Just - Hatmaker process, from collecting boxes	750 to 1,250
Supplee & Alsbaugh (229)	Just - Hatmaker process, direct from drums	561
Supplee & Alsbaugh (229)	Just - Hatmaker process, after sifting	1614
Supplee & Alsbaugh (229)	Just - Hatmaker process, after packing	3271
Macy (224)	Domestic brands	40 to 2,200
Macy (224)	Foreign brands	240 to 7,900

The above table clearly shows the marked difference in germ content of milk powders between the spray-drying process and the film-drying process. With the exception of the Kunick drum dryer which uses temperatures below the boiling point of water, none of the drum powders contained more than 6,000 bacteria per gram, while the spray-dried powders yielded counts ranging from 5,000 to 5,500,000 bacteria per gram of powder. The reason for the lower germ content of the drum-dried milk is obvious. Direct contact of the thin milk film with the metal surface of the steam-heated drum subjects the milk to higher temperatures than is possible with the milk spray dispersed in the heated air where the velocity of evaporation is such as to actually exert a cooling effect on the minute milk particles.

In the case of powders from either process, the product taken direct from the dryer gave a much lower count than the same powder after packing. This suggests that the powder is subject to considerable contamination incident to handling between dryer and final package.

Effect of Storage on Bacterial Content of Milk Powders.—As previously stated, the low moisture content of powdered milk precludes bacterial development in storage. With increasing age the number of bacteria decrease. This decrease is continuous, as shown by Supplee and Alsbaugh[229] in Table 48 and by Macy[224] in Table 49.

Table 48.—Bacterial Counts of High and Low Moisture Milk Powder When Fresh and After Storage. (Supplee and Alsbaugh).

Series	Moisture Percent	Bacteria per Gram Dried Milk						
		Fresh	2 Mos.	4 Mos.	6 Mos.	8 Mos.	10 Mos.	12 Mos.
X Average 43 Samples	4.91	22,508	7,818	2,487	655	412	354	261
XX Average 9 Samples	2.65	8,022	4,172	2,616	622	383	277	262
XXX Average 9 Samples	7.04	34,533	12,216	1,850	677	366	361	256

X Average of all samples.
XX Average of lowest moisture sample of each of 9 series.
XXX Average of highest moisture sample of each of 9 series.

The above table shows the continuous decrease of bacteria with advancing age of powder. The figures further show a higher count for high-moisture powder than for low-moisture powder while fresh, but by the fourth month all powders show a similar count, regardless of moisture content.

Table 49.—Reduction in Bacteria of Spray-Dried and Drum-Dried Powder in Storage. (Macy).

Type of Dried Milk	After Storage at Room Temperature for						
	6 Mos.	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Spray-dried	56.3	90.7	93.9	97.4	99.2	99.9	99.9
Drum-dried	60.0	96.0	97.6	97.9	97.9		

The figures in the above table show that the bacterial content of both types of powder decreases with age. This reduction appears to be somewhat more rapid in the drum-dried powder during the early part of storage than in spray-dried powder. During prolonged storage, however, the decrease of bacteria in the spray powder is somewhat greater than in the drum powder.

Effect of Temperature of Storage on Reduction of Bacteria.—The reduction of bacteria increases with rising storage temperature, as shown by Macy[224] whose results are given in Table 50.

Table 50.—Effect of Storage Temperature on Bacterial Content of Dried Milk. (Macy).

Type of Dried Milk	Temperature of Storage		Number of Bacteria per Gram		Reduction
			Original	After 1 Year	
	°C	°F			Percent
Spray powder (pressure spray)	5	41	33,500	4,100	87.7
	10	50		1,500	95.2
	20	68		1,200	96.4
	37	98.6		900	97.3
Spray powder (centrifugal)	5	41	27,600	3,700	86.6
	10	50		2,000	92.7
	20	68		1,500	94.5
	37	98.6		1,000	96.4
Drum powder	5	41	2,200	50	96.8
	10	50		100	95.4
	20	68		100	95.4
	37	98.6		50	96.8

The results tabulated above show that in the case of spray powder the reduction of bacteria was greatest at 98.6°F. and least at 41°F. In the case of the drum powder with its relatively low initial bacterial count, the different storage temperatures did not reflect any consistent influence on bacterial reduction. Macy suggests that this may be due to the probability that it is largely only the resistant types of bacteria that originally survive this drying process. In the spray-dried powder a large number of the less resistant acid bacteria survive and their subsequent destruction with increasing storage temperature causes a marked reduction in total count.

Types of Bacteria in Dried Milk.—The bacterial flora of both spray-dried and drum-dried powder was studied by Macy[224] qualitatively. His results are in harmony with what may reasonably be expected from the heat treatment of the two processes. The spray powder, not having suffered direct contact with high-temperature metal surfaces, shows a predominance of acid-producing types. In the drum powder the acid bacteria have largely disappeared, therefore the species left are principally those of the more heat-resistant peptonizing groups.

Macy's observations of the bacterial flora of drum-dried milk are supported by the earlier results of Delepine,[221] Supplee and Alsbaugh,[229] and Hunwicke and Jephcott,[230] to the effect that the drum-drying process (Just-Hatmaker type) is capable of completely destroying non-sporing bacteria. Supplee and Alsbaugh found the organisms present in drum powder to show a large percentage of sporing bacteria of the B. mesentericus and B. subtilis types. Coccus forms, and yeast and molds were also present. Delepine, and Hunwicke and Jephcott found that B. tuberculosis is either destroyed or rendered completely avirulent by the drum-drying process. Jephcott, Hunwicke and Ratcliffe[231] further point out that the study of the number and type of bacteria in drum-dried milk furnish a useful index to the purity of dried milk and is helpful in checking contamination during the manufacture and subsequent handling of the product.

As previously explained, bacterial action in the milk powder itself is made impossible because of lack of the necessary moisture. The bacterial content of milk powder, therefore, is a negligible factor from the standpoint of keeping quality. Nevertheless, the aspect of the wholesomeness of the dried milk and its freedom from objectionable fermentation when the product is reconstituted compel such attention to sanitation in its manufacture and handling as to preclude promiscuous contamination and to insure its freedom from bacteria that may jeopardize its usefulness for industrial purposes and its wholesomeness as a human food.

VITAMINS IN MILK POWDERS

In the use of milk powder as a substitute for fluid milk the question of vitamin potency demands serious attention. Its importance is of especial magnitude with relation to the feeding of infants and invalids. The literature is replete with experimental data on this subject. Unfortunately, the great mass of available information is so pregnant with contradictory results, as to greatly detract from its usefulness and value.

The confusing lack of uniformity of experimental results and of their interpretations is in large part due to the incompleteness of records as to origin of raw material, process of manufacture and details of treatment during manufacture and incident to storage. Extensive research work dealing with the vitamin content of milk has amply demonstrated the presence of wide fluctuations according to source. It is well known that the vitamin strength of the fluid milk varies with locality and season of year, as determined by breed, period of lactation and feed. It is also known that the time-temperature relationship in manufacture and the oxygen absorption in storage are important factors in the determination of the preservation of some of the milk vitamins. Because of these facts it is obvious that results of experiments in which these various factors are either not known or are ignored, must be pregnant with a multitude of contradictions, rendering their interpretations of doubtful value.

It is beyond the scope of this volume to interpret and discuss in detail the maze of available conflicting experimental results. The present discussion is, therefore, confined to a brief summary of what appears to be the vitamin situation of milk powder, as judged from our general knowledge of vitamin resistance and as supplemented by the limited experimental results of apparently dependable nature.

Vitamin A.—This vitamin, being resistant to heat but susceptible to the destructive influence of oxidation reactions appears to survive the process of heat treatment both in spray drying and in drum drying. Freshly made powders of either process retain the vitamin A potency of the original milk. If exposed to prolonged contact with air after manufacture they may tend to diminish in vitamin A strength with age. The spray powders are somewhat more sensitive to air exposure on account of their porosity. If packed in air-tight, moisture-proof containers, and especially if vacuumized or packed in an atmosphere of nitrogen the powders of both processes may be expected to retain their full vitamin A strength for a prolonged period of time.

Vitamin B. (B_1 and G).—Vitamin B_1 is more sensitive to heat treatment than vitamin G. The tendency is for vitamin B_1 strength to diminish somewhat in both the spray powder and the drum powder, while vitamin G may be expected to be present in both powders in strength equivalent, or practically so, to the vitamin G strength of the original milk. Neither vitamin B_1 nor G is susceptible to oxidation reactions and their weakening with advancing age of the powder is improbable.

Vitamin C.—This vitamin is very sensitive to heat, especially in the presence of air and of metallic catalysts. It is readily destroyed by such heat treatment as is given the milk in the process of desiccation. It may be expected, therefore, that all dried milk is deficient in antiscorbutic properties. This assumption is supported by the bulk of experimental data on record.

Vitamin D.—Experimental data showing the resistance of this vitamin to heat are too meagre to justify conclusions. Whether the heat treatment of desiccation and other conditions incident to manufacture and storage are detrimental to vitamin D is uncertain. The majority of feeding experiments suggest that milk powder from either the spray or drum process does not contain sufficient vitamin D strength to prevent rickets. On the other hand, Blackham[170] reports that the speakers (most of whom were medical officers of important towns) at the Birmingham Congress of the Royal Sanitary Institute in 1920, agreed that they had never seen a case of rickets or scurvy in a child fed on dried milk. Dried milk may be made anti-rachitic, however, by the addition to the fluid milk of viosterol or of cod liver oil or halibut liver oil, or by irradiation with ultra-violet light, as shown by De Sanctis, Ashton and Stringfield[232] or by irradiation of the fluid milk with the carbon arc lamp, as demonstrated by Hess and Lewis.[233] For details of process of irradiation see Chapter XII on "Irradiation of Evaporated Milk."

Vitamin Value of Dried Milk as a Supplementary Food.—An unbiased appraisal of the vitamin potency of dried milk should recognize the fact that there are wide variations in the vitamin strength of fluid milk from different sources. Furthermore, average fluid milk is deficient in some of the vitamins and fails to supply the full vitamin requirements of the diet. This applies particularly to vitamin C and D. The natural vitamin strength of milk powder is no greater than its equivalent of the original milk before desiccation. As pointed out in previous paragraphs, some of the vitamins are more or less sensitive to the process of manufacture and to that extent desiccation may lower the vitamin potency of the dried milk below that of the original fluid milk.

The great value of milk powder lies in its use as a supplementary food for the diet, and as such its vitamin content is usually adequate as attested by most of the results recorded of practical feeding experiments of which the following is a typical example:

McCollum, Parsons and Kalmbach[234] in a series of experiments with 84 children, some of whom were tubercular and most of whom suffered from malnutrition, found that milk in the form of dried milk (spray process milk) proved an effective supplementary food for a dietary selected from cereals, tubers, fleshy roots, and meats, which diet without milk did not prove satisfactory for the physical development and behavior of the children under experiment.

For a more detailed discussion of the vitamins of milk see Chapter XXIV.

DIGESTIBILITY OF MILK POWDER

The digestibility of dried milk has been found to be very high and for this reason, as well as because of its uniformity of composition and relative freedom from profuse bacterial contamination, dried milk is looked upon by the medical profession as a highly satisfactory substitute for fresh milk, where fresh milk of good quality is not available. Dr. R. J. Blackham[170] of London, England, and of late, honorary surgeon to the Viceroy of India, who over a period of 15 years was in charge of the Government Laboratories in India, writes as follows:

"With regard to digestibility there can be no two opinions as to the virtues of dried milk in this direction. Goodhart and Hill say: 'The chief value of dried milk lies in the fineness and softness of the curd formed by it, which is so much more digestible than that of fresh milk that some infants who cannot digest fresh milk, or even peptonized milk, will thrive on dried milk.'

"In digestive troubles waterless milk is extensively prescribed by leading British physicians, and many French and Belgian doctors regard it as 'un veritable aliment de choix' (a preferred food) for such conditions.

"In the discussion which followed my paper on dried milk at the Birmingham Congress of the Royal Sanitary Institute, the value of the product in the dietary of typhoid fever and other specific fevers was emphasized; and after considerable experience in the employment of the products in various parts of the world, I have no hesitation in stating that it is much better than ordinary milk in this type of disease, and medical men who used it at my suggestion in Ireland, where typhoid is not uncommon, were greatly pleased with the results.

"There is another type of persons with whom the use of dried milk is increasing, namely, nursing mothers.

"Parallel with the development of the employment of dried milk in infant feeding, there has been a remarkable decrease of the infantile mortality in Great Britain.

"Dr. Robert Hutchison, the eminent authority on feed and dietetics, said: 'I am of the opinion that no inconsiderable part of the decline in deaths from infantile diarrhea which has happily taken place in recent years is due to the ever-increasing use of dried milk for infant feeding, especially among the working classes.'

"It has been estimated that since its introduction on a commercial scale some 15 years ago, the use of dried milk in welfare centers and in various institutions has increased more than 150 per cent, and during the same period the rate of infantile mortality for England and Wales has fallen 43 per cent, etc."

In another paper Dr. Blackham[235] reported his experience in the tropics and says: "Dried milk is superior to fresh tropical milk in nutritional value and especially adapted to supplement breast feeding."

Dr. Wm. E. Deeks,[169] General Manager, Medical Department, United Fruit Co., New York City, states that the use of powdered milks in the tropics forms a very satisfactory means of preparing infant's food. He recommends "Klim," a spray powder, with which he had experience and suggests the following formula:

Table 51.—Formula for Preparation of Infant Food from Milk Powder

Age of Infant	Daily Amount Necessary Ounces	Milk Powder (Klim) Teaspoonfuls	Cane Sugar Milk Sugar or Dextrimaltose Teaspoonfuls	Water Sufficient to Make Ounces	Amount of Each Feeding Ounces	Interval of Feeding Hours	Number of Feedings Daily
1 day.......	1- 4	....	....	1- 4	¼- ½	2-4	4- 8
2 days......	6	2	2½	6	½- 1	2	6- 8
3 days......	10	4	4	10	½- 1	2	8-10
4 days......	11	6	4	11	1 - 1½	2	10
5 days......	13	8	5	13	1 - 1½	2	10
6 days......	14	10	5	14	1½	2	8-10
7 days......	15	14	5	15	1½- 2	2	8
1 to 4 weeks..	15-25	*4- 7	5- 7	15-25	2 - 3½	2½	8
1 to 3 months.	25-35	*7-10	7-10	25-35	4 - 5	2½	6- 7
3 to 6 months	40	*11-14	12-14	40-50	6 - 8	3	6
6 to 12 months	50	*14	14	50	8 -10	3-4	5- 6

* Tablespoonfuls.

NOTE.—

4 level teaspoonfuls (Klim)	= 1 level tablespoonful.
2 level tablespoonfuls (Klim)	= 1 ounce by measure.
4 level tablespoonfuls (Klim)	= 1 ounce by weight.
9 level teaspoonfuls of milk-sugar	= 1 ounce by weight.

(In the preparation of all of the above formulæ, an 8-ounce graduate saves time.)

Preparation.—The measured quantity of sugar (milk sugar, cane sugar or dextrimaltose) should be added to the measured quantity of warm water, and after solution, the measured quantity of milk powder stirred in and dissolved.

Fruit Juice.—Beginning about the seventh day ten drops of orange juice is given each morning before the first feeding and the quantity gradually increased so that at the end of the first month a teaspoonful is given daily, and the quantity increased at the rate of a teaspoonful a month so that at the end of the year the child is getting one and one-half ounces daily. If orange juice is not available, the juice of other fruits, or of fresh or canned tomatoes, may be used.

Lime Water.—From one to two teaspoonfuls is added to each nursing bottle just before the nipple is adjusted. If constipation is present this may be substituted by a teaspoonful of milk of magnesia for one or two feedings.

After the child is four months old barley-water can be gradually substituted for the water in the formula, and at the age of nine months some oatmeal jelly can be added instead of barley-water.

Miyawaki, Kanazawa and Kanda[236] studied the protein digestibility of spray process and drum process powders, experimenting with both peptic digestion and feeding trials with white rats. All samples showed a high digestibility. The drying tended to increase rather than to decrease protein digestibility. In both experiments the spray-dried powder proved more digestible than the drum-dried powder. In the feeding experiments the difference in digestibility between the two powders was very slight. The protein digestibility increased with acidity. Dried milk from the freshly opened package was more digestible than dried milk from the same package four weeks after opening. The decrease in digestibility due to air exposure was much greater in drum-dried powder than in spray-dried powder. The use of neutralizers and the addition of sucrose diminished the digestibility of the powder.

The infant feeding experiment reported by Perez[237] offers further evidence of the dietary value of milk powder. A comparative study of 265 infants was made. Of this group 85 were fed on condensed milk, 68 on fresh fluid milk, 43 on canned fluid milk, and 69 on powdered whole milk (spray process). Perez reports that by far the best results were obtained on the dried milk formulas. While no specific report is available on the digestibility results of this experiment, the superiority of performance of the powdered whole milk precludes the possibility of impaired digestibility.

CHAPTER XXXII

THE KEEPING QUALITY OF MILK POWDER

The effect of age and moisture content on the physical properties of milk powder, of which solubility is the most important, was discussed in Chapter XXXI. The term "keeping quality," as here used, refers to the preservation of the flavor and odor of dried milk. Under the caption "Bacteriology of Milk Powder" it was shown that the low moisture content inhibits all bacterial activity and that the germ content of the dried product is therefore not a factor in the determination of its keeping quality. The factors that control age deterioration of milk powder have to do largely with reactions of a chemical nature, that may be incited or accelerated by a variety of factors and combinations of factors, such as freshness of milk and of milk fat, treatment of milk preparatory to desiccation, method of drying, percentage composition of dried milk with particular reference to acid, fat and moisture, presence of metallic catalyzers, heat exposure after drying, character of atmosphere in which the powder is stored, temperature of storage and nature of container. The important reactions responsible for age deterioration embrace enzymic, hydrolytic, catalytic and oxidative changes. The most common flavor and odor defects involved in progressive age deterioration are: stale, musty and storage flavor, rancidity, tallowiness, and in rare cases, fishiness.

Stale, Musty and Storage Flavor and Odor.—The stale flavor and odor is a characteristic age defect of all milk powders. It is capable of appearing in both skimmilk powders and whole milk powders. The rapidity of its development appears to depend largely on the moisture content of the powder, the period of exposure to the drying heat after manufacture, and the temperature and air protection during storage. The appearance of stale flavor is hastened by increased humidity, whether due to high original moisture content or moisture absorbed from the atmosphere during storage.

In the presence of excess moisture, milk powder tends to become lumpy, moldy, and to develop such off-flavors as stale, musty and storage flavor with age. The development of these defects is hastened and intensified by high storage temperatures. Moderately low storage temperatures retard them. Very low storage temperatures (32°F. or below) are likewise objectionable, as they tend to favor the development of a disagreeable musty storage flavor.

Accurate experimental data showing the nature of the reaction and the constituents envolved in the development of this defect are lacking. It is believed that they have to do with physico-chemical changes of the protein constituents of the dried milk. The appearance of the defect is best prevented by protection against air and moisture and by avoiding extremes of high and low storage temperatures.

The stale, musty and storage flavor appears to be more prevalent among atmospheric drum powders than spray powders. This is very probably due to the fact that this age defect has to do with protein reactions, which are intensified by the higher moisture content of drum powder and by the higher temperatures to which the milk is exposed in drum-drying.

Rancid Flavor and Odor.—Rancidity in milk powder resembles the pungent, "rasping" odor of butyric acid. It is the result of fat hydrolysis causing the liberation of some of the volatile fatty acids of which butyric is the most important. The hydrolysis of the glycerides is believed to be due to the presence of the fat-splitting enzyme lipase. It is a disputed question whether lipase is an inherent enzyme of milk, but it is well known that numerous species of bacteria not infrequently associated with milk, and also some species of molds, are capable of secreting lipolytic (fat-splitting) enzymes.

Enzymes do not depend on the presence of moisture for their action. The desiccation of milk, therefore, provides no protection against enzymic reactions, and experimental evidence is fairly conclusive that it is the lipolytic enzymes which are responsible for rancidity in milk powder containing milk fat. These deductions are further supported by the work of Supplee[193] who introduced lipolytic enzymes into low-moisture Just process powder. Powder so inoculated developed intense rancidity in a few weeks while untreated check samples of the same powder produced no rancidity.

The bacterial origin of lipolytic enzymes suggests that the freshness and freedom from contamination of the fluid milk before manufacture may have a marked influence on the development of rancidity in the milk powder. This assumption is strongly supported by commercial experience. Fleming and Nair[82] also report that long experience has shown that high acid milk taken in at the receiving platform continues to develop acidity so rapidly that milk powder dried from it has a peculiarly disagreeable acid flavor.

Because enzymes are destroyed or rendered inactive in the presence of high temperatures, the process of manufacture is a determining factor in the development of rancidity after manufacture. Rogers, Berg and Davis[238] showed that the activity of lipase is greatly weakened when milk is heated to 66°C. (150.8°F.) and is destroyed at 80°C. (176°F.). It is conceivable, however, that the higher concentrations of milk, such as are employed in the drying process, exert a protective influence on the enzyme and render it somewhat more resistant to heat.

As the result of the destructive effect of high temperatures on lipase, whole milk powders made by the high temperature atmospheric drum-drying process develop rancidity rarely, if ever. Spray-dried powders, in which the pre-heating temperature of the milk is usually confined to a range of 140° to 160°F., on the other hand, are more prone to become rancid with age, suggesting that the lipolytic enzymes may survive the heat treatment of the spray process.

For further substantiation of the above commercial experiences may be cited the researches of Dahle and Palmer[239] who applied the Storch test to milk powders. They invariably found no peroxidase activity in atmospheric drum powder, while vacuum drum powders and spray-process powders retained their peroxidase activity. The enzyme peroxidase surrenders its activity at approximately 175°F.

Nair[249] who studied the presence of lipase in raw, pasteurized milk and desiccated milk could detect no lipase in powdered whole or skimmilk desiccated by a drying system in which the fluid milk was pre-heated at 63-64.5°C. (145.4-148.1°F.) for thirty minutes. He concluded that rancid odors and flavors may be expected to develop in manufactured milk products if fluid milk is not subjected to sufficient heat treatment for inactivation of lipase.

The theories, observations and facts above cited, suggest two principal avenues for the control or prevention of rancidity in whole milk powder, namely, the use of sufficiently high temperatures in manufacture to insure the destruction of lipolytic enzymes present in milk, and efficient control of the quality of the fresh milk. The promiscuous raising of the temperature of the heat treatment of low-temperature drying processes jeopardizes the solubility of the finished product. However, pre-heating at temperatures sufficiently high to render the lipase inactive can be so controlled as to avoid serious injury to the solubility of the powder. Efforts toward more effective control of the quality of the fresh milk are bound to materially assist in further minimizing the tendency toward the development of rancidity.

Tallowy Flavor and Odor.—This is by far the most prevalent age defect of milk powders containing milk fat. Tallowy milk powder has a distinct flavor and odor that suggests spoiled tallow. It is brought about by oxidative processes associated with the milk fat similarly as in the case of tallowy butter.

Tallowiness is frequently confused with rancidity. With the exception that both defects have to do with changes of the milk fat, they are due to separate and distinctly different reactions and products. Unlike rancidity, which deals with the presence of free fatty acids which are volatile and which are the result of hydrolysis of the glycerides, tallowiness is the product of oxidation; it is usually accompanied by the bleaching of the fat and the tallowy flavor and odor are not volatile. In steam distillation they remain in the residue, they are not present in the distillate, as shown by Hunziker and Hosman.[4]

Our knowledge regarding the specific reactions which are responsible for the characteristic tallowy flavor and odor is incomplete. The development of tallowiness in milk fat was studied by Holm and Greenbank,[194, 287] Supplee,[193] Hunziker and Hosman,[4] and Holm, Greenbank and Deysher.[240] The results of these investigations indicate that it is especially the fatty acid radicals of the unsaturated fats, such as the oleic acid, that are involved. When oleic acid takes up oxygen, a tallowy product results. The absorption of exceedingly small amounts of oxygen, too small to noticeably affect the iodine absorption number, is capable of producing intense tallowiness, and there is apparently but little difference in degree of tallowiness between slightly oxidized and highly oxidized fat.

Furthermore, milk fat when in contact with oxygen or air, passes through a period during which oxygen absorption, while not entirely absent, is very slow and practically imperceptible. This is called the induction period. During this period the fat remains free from tallowiness. The length of the induction period is influenced by temperature. It is longest at low temperatures and decreases as the temperature rises. As the induction period progresses, the resistance of the fat to oxidation diminishes. While definite experimental data showing the nature of reactions that occur during this period are lacking, it is believed that the induction period is accompanied by a slight absorption of oxygen and the formation of compounds of increased oxidizing intensity. The induction period is usually followed by rapid oxygen absorption and the appearance of an intense tallowy flavor and odor.

Effect of Air on Tallowiness.—Since tallowiness is caused by oxidation it follows that exposure of the milk powder to air hastens the defect. Keeping milk powder containing milk fat exposed to air, or in containers that are not air-tight, causes the product to become tallowy rapidly. This is a fact well known to the manufacturer. Greater attention to the air-tightness of the container within recent years, and packing the power in vacuo or in an atmosphere of an inert gas such as nitrogen, has been instrumental in materially delaying deterioration and improving the keeping quality of whole milk powders and cream powders.

It has been found, however, that the presence of even exceedingly small amounts of oxygen, including dissolved oxygen as well as free oxygen, will cause the tallowy defect. The results of Holm, Greenbank and Deysher[240] indicate further the presence of loosely bound oxygen compounds, called moloxides, in butter oil. Experiments with butter oil and milk powder packed in vacua showed that oxidation leading to deterioration and tallowiness is not entirely arrested even in a vacuum, and it is believed that the presence of moloxides is responsible for these observations. This assumption is further supported by the fact that there was no oxidation in steam-treated samples exposed to light under vacuum, while unsteamed samples held under identical conditions suffered oxidation, suggesting that steam treatment eliminated the moloxides as a cause of deterioration due to oxidation.

The prevention of tallowiness in milk powder is further complicated by the extremely fine state of division and by the character of the dried milk particles, causing them to present a relatively large surface to air contact. Palmer and Dahle[241] show that in the case of the spray powder each particle contains in its center an air cell. In these particles the fat is therefore exposed to air both from within and from without the granule. They found these air cores to be larger in centrifugal spray powder (Dick process) than in pressure spray powders. No air cells were observed in the granules of drum powder. On the basis of these findings these investigators are inclined to attribute the generally observed greater tendency of spray powders to turn tallowy than drum powders to the presence of the air core in the former. On similar grounds they hold that the inferior quality of centrifugal spray powder (Dick process), as compared with pressure spray powder, may be due to the larger air core in the particles of the former. As will be shown under "Effect of Pre-Condensing," the air core and porosity of spray powders is greatest when spraying uncondensed milk. Pre-condensed milk yields less porous particles with smaller air cells, and to that extent such powders should be less susceptible to oxidative deterioration.

With reference to packing in an atmosphere of inert gas, experiments show that hydrogen and nitrogen are very effective in retarding oxidation and spoilage. Carbon dioxide, on the other hand, failed to preserve the dried milk better than atmospheric air. Holm, Wright and Greenbank[242] point out that CO_2 will hydrolize soaps in the presence of water and will probably act similarly upon glycerides. Their results with milk powders stored in CO_2 appear to indicate that this gas connot be considered an inert gas toward dairy products containing milk fat. They further hold that storage in nitrogen or in vacuum reduces the tendency to deterioration but should not be considered an absolute safeguard to prevent oxidation changes.

Effect of Light on Tallowiness.—That light accelerates oxidative changes is well known. The direct rays of sunlight intensify the oxidizing action of the air. Light has a bleaching effect on pure milk fat and on butter. This effect is invariably preceded or accompanied by the appearance of an intense tallowy flavor. The ultraviolet rays, especially, have a powerful effect upon the susceptibility of fats to oxidation. Exposure of milk powder containing milk fat, in the presence of air, to light increases the tendency toward the development of tallowy flavor.

Exclusion of light is one of the essentials to keeping quality of all dairy products containing milk fat. Dried milk, and especially whole milk powder and cream powder, if held for a considerable time in the factory before packing, should be kept in the dark. Remnant barrels and other "broken" packages in the factory or in the user's establishment should be kept tightly covered. The tightly covered barrel and the hermetically sealed tin provide satisfactory protection against the deteriorating effect of light. Glass containers should be of a color that shuts out ultraviolet light.

Effect of Heat on Tallowiness.—The temperature of storage is an important factor in the development of tallowy flavor and odor of milk powder containing milk fat. Heat intensifies and accelerates most chemical reactions. It shortens the induction period of the fat in dried milk, hastens oxidation and shortens the time before the powder becomes tallowy. At temperatures only slightly above the freezing point, milk powder will keep fresh, other conditions being normal, for a prolonged period of time, while at temperatures at or above room temperature the same powders may show tallowiness in a few months. The intensity of the tallowiness increases rapidly at the higher temperatures.

Dahle and Palmer[243] studied the keeping quality of milk powders stored in different type packages at 4, 20 and 37°C. (39.2, 68 and 98.6°F.), respectively, examining the samples at intervals of 3 months. All samples stored at 37°C. were very tallowy and discolored at the first examination (3 months). At 20°C. most of the samples showed slight tallowiness in 9 months, which became somewhat more marked in 12 months. At 4°C. only one sample had developed tallowiness in 9 months and none showed this defect in 12 months, though in most cases a stale flavor was reported at this age. In subsequent experiments these investigators noted considerable difference of the effect of temperature between powder kept in air-tight and those kept in pervious containers. The injurious effect of high temperature was not as marked in the air-tight samples as in the others. As the result of these experiments they concluded that there was no great difference in the rapidity with which tallowiness occurred between 4°C. and 20°C., but that deterioration was rapid at 37°C.

The above results agree in general with those of Supplee[193] but this investigator reports a marked difference in results between the temperature of the freezing point and ordinary temperature. He found that at 32°F. the appearance of tallowiness in partially skimmed milk powder was prevented for over 18 months, at 52°F. there was evidence of tallowiness in 12 to 13 months, and at 70 to 75°F. tallowiness occurred in 5 to 6 months. Supplee also reports that the intensity of tallowiness rapidly increases at the higher temperatures and that it was possible, even after its first appearance, to promptly arrest its rate of development by removal to a low temperature. Holm, Wright and Greenbank[242] likewise found that storage at 20°C. (68°F.) caused relatively rapid deterioration as compared with the rate of deterioration at 0°C. and 10°C. (32°F. and 50°F.), respectively.

These results show conclusively that the danger of developing tallowiness is very great at or above ordinary temperatures and that this defect can be greatly delayed and its intensity minimized by storing milk powder containing milk fat in the cold.

For similar reasons it would appear that prolonged exposure of the powder to the drying heat would be very detrimental from the standpoint of the tallowy condition. Permitting the spray powder of an entire day's run to lie in the hot drying chamber, as occurs in some of the factories, provides excellent conditions for the induction of oxidation that leads to early manifestation of tallowiness in subsequent storage.

Even in factories where the dried milk is continuously removed from the drying chamber, but is immediately packed into barrels without previous cooling, the drying heat will stay with the powder for several days. During this time the heat in the powder will tend to shorten the induction period of the fat and to hasten oxidation that leads to the early development of tallowiness.

In the more improved installations and processes of spray-drying, the dried milk is not only removed from the hot drying chamber as fast as it settles into the hopper, but on its journey to the barrel it is cooled to near room temperature. This precaution is especially desirable in the case of whole milk powder and cream powder.

Effect of Moisture on Tallowiness.—It was shown earlier in this chapter that high moisture in milk powder causes objectionable lumping and caking, may invite moldiness, destroys solubility, and accelerates the development of a stale flavor. These age defects are caused by changes in the properties of the milk proteins. High moisture powders also are prone to develop fishy flavor as the result of hydrolysis of the nitrogen base (cholin) in the lecithin. In the case of tallowiness which is the result of oxidation of the milk fat, on the other hand, the presence of moisture has the opposite effect. It retards oxidation of the milk fat, tending to decrease the quantity of compounds such as aldehydes and ketones which form the tallowy character. Extremely dry milk powders develop tallowy flavor and odor more rapidly and more intensely than milk powders of normal or of high moisture content.

According to Supplee,[193] Supplee and Bellis,[218] and Holm and Greenbank,[194, 240] chemical studies of the milk fat, however, showed equal progress of oxidation for both low moisture and high moisture products. Holm and Greenbank further concede that the moisture content is not altogether a controlling factor, and Supplee suggests that "in powders containing excessive moisture the tallowy condition may be masked to a degree which renders it nearly unrecognizable."

Holm and Greenbank,[240] as the result of later work, conclude that there is an optimum moisture content for preventing tallowiness insofar as this defect is controlled by humidity. Their moisture-vapor pressure equilibrium curve shows this optimum to lie between approximately 1.88 and 4.0 per cent moisture, and indicates that below this range lies the region conducive to tallowiness, and above this range lies the region conducive to fishiness, caking, etc. They further point out that the different processes of drying yield powders with different avidities for moisture and that 1.88 per cent moisture represents the approximate optimum for spray powders, while for drum powders the optimum moisture content is approximately 3 per cent.

Effect of Per Cent Fat on Tallowiness.—Since tallowiness is a defect resulting from oxidation affecting the milk fat, and since skimmilk powders which contain ordinarily a small amount of milk fat (about 1 to 1.5 per cent) are not subject to this defect nearly as much as whole milk powders, it should naturally follow that the higher the percentage of fat in milk powder, the greater the danger and the more rapid the development of the tallowy condition.

Experimental results of different investigators are at variance on this point. Thus Supplee[193] reports that, beyond certain limits of fat content, the higher the fat content, the longer the time before tallowiness makes its appearance. Supplee's results are summarized in Table 52.

Table 52.—Effect of Fat Content on Length of Time Before Milk Powders Become Tallowy at Room Temperature

Kind of Milk	Per Cent Fat in Powder	Time to Produce Tallowy Condition
About ¾ skimmed	5% to 6%	Almost always tallowy after 3 to 4 months
½ skimmed	12% to 13%	Rarely under 5 to 6 months, more often not until 7 to 8 months
Whole milk	26% to 27%	Kept satisfactorily for 12 to 13 months
Thin cream	50% to 55%	Kept satisfactorily for 15 to 18 months

The results of work by Holm, Greenbank and Deysher[244] are in direct contradiction of Supplee's findings. They show a perceptible decrease of keeping quality with increased fat content, especially "within the higher ranges." Later Holm and Greenbank[240] further report that "Increased fat content of the powder increases the susceptibility of the product to oxidation. Above 24 per cent fat content the increase in susceptibility is rapid with additional fat increases."

Disregarding the contradictory experimental data above cited, it appears logical to assume that, other conditions being the same, an increase in fat content augments the tendency of fat oxidation, hastens the appearance of tallowiness and increases the intensity of this defect. The fact that some of the experimental results contradict this general conclusion must be attributed to the presence of other factors that overshadow the effect of the per cent fat. In this instance it appears probable that the clarifying effect of centrifugal separation in the case of Supplee's cream powders is responsible for their greater resistance to fat oxidation than the lower-fat whole milk powders which, not requiring separation, are without the benefit of purification by centrifugal force. More recent work by Holm, Greenbank and Deysher[245] shows that clarification eliminates agencies that hasten fat oxidation, and that milk powder made from clarified milk does in fact keep better. See also "Effect of Clarifying on Tallowiness."

Effect of Acidity on Tallowiness.—Acidity hastens and intensifies the reactions that lead to tallowiness. It is especially the fatty acids that act as catalyzers in the reaction. Even exceedingly small additions of acids, barely perceptible to titration, materially change the susceptibility of the fat to oxidation. It is for this reason that the freshness and quality of the fresh milk is a dominating factor in determining the keeping quality and resistance to oxidation of the resulting powder. Age increases the acid value of milk fat. The extent of this change is further augmented by improper handling and holding of the fluid milk, such as insanitary conditions that invite profuse bacterial contamination and high temperatures that encourage rapid bacterial development. Powder made from such milk usually has poor keeping quality, yielding readily to oxidation and showing the tallowy character early.

The dominant role of fatty acids in the susceptibility or resistance of the fat to oxidation is emphasized by Holm and Greenbank.[194] They show that washing improved the keeping quality of the fat and steam distillation was still more effective in retarding oxidation. They sealed the samples in vacua and placed them in strong sunlight. The check sample (untreated) bleached in from 7 to 10 days, while the washed and the steam-distilled samples, respectively, showed no change in two months.

The process of drying may aso become a factor in controlling subsequent oxidation in the finished product, insofar as it may eliminate acids from the drying milk. The greater heat and the direct contact of the milk with high-temperature metal heating surfaces of the atmospheric drum-drying process suggest greater possibilities for expulsion of acids than the spray process with its absence of metal heating surfaces and its great velocity of evaporation that precludes high milk temperature. It has, in fact, been the general experience of the manufacturer and dealer that film-dried or drum-dried milk powder does not become tallowy as readily as spray-dried powder.

Effect of Metallic Catalyzers on Tallowiness.—Certain metals and their salts and oxides, because of their action as oxidizers and catalyzers, are capable of hastening oxidation and the development of tallowiness and related flavor defects in dairy products containing milk fat. Especially copper and its salts and the salts of alloys containing copper, such as German silver, etc., are active in this repect. Iron also is a catalyst but it is less active. Tin and nickel appear to have no noticeable effect.

Rogers, Berg, Potteiger and Davis[246] found that the salts of copper have a marked accelerating action on the rate of deterioration of butter. Hunziker and Hosman[4] demonstrated that iron and especially copper, their lactates and their hydrates and the hydrates of German silver and of brass, when in contact with butter, developed a disagreeable, tallowy flavor in butter and caused bleaching.

Supplee[193] states that copper in the form of organic salts, when introduced into dry powder or into milk before drying, caused early manifestation of tallowness. He found that when such salts were incorporated in the liquid milk at the rate of 10 to 15 parts of copper per million parts of milk solids, tallowiness invariably developed within 50 days at room temperature. When introduced at the rate of 100 to 200 parts per million, the powder showed the tallowy condition in a much shorter time. The following figures, Table 53, derived from Supplee's work, show the effect of different amounts of copper taken up by milk on the rapidity with which tallowiness manifested itself in the milk powder.

Experiments with metallic iron and iron salts showed that the effect on the keeping quality of milk powder containing fat pointed in the same direction as in the case of copper and copper salts, but the action was much less pronounced. This was offset, in part at least, by the fact that iron was taken up by the milk in much larger quantities than copper.

Briggs[247] who found metallic catalysts to have a marked effect in hastening fat autoxidation, places them in the following order according to intensity of action: copper lactate, iron lactate, nickel sulphate. Zinc lactate retarded fat oxidation. Curd also had an anti-oxygenic effect.

Table 53.—Comparison of Keeping Quality of Whole-Milk Powder Containing Different Amounts of Copper, with Untreated Milk Containing no Copper

Powder Made from Milk Containing Varying Amounts of Copper		Powder Made from Milk Containing no Copper
Parts Copper per Million Parts Milk Solids	Time When Tallowy	Time When Tallowy
0.7 to 1 pt.	9 to 10 months	12 months
3 to 7 pts.	5 to 7 months	over 12 months

The above citations unanimously show the damaging effect of metal surfaces in equipment used for pre-heating, pre-con-hastening fat oxidation and the appearance of tallowiness. They emphasize the importance of intelligent attention to the choice of metal surfaces in equipment used for pre-heating, pre-condensing and desiccating milk. For further details on metals see Chapter II, "Metals in Condensery and Milk Powder Equipment."

Effect of Character of Powder Grain on Tallowiness.—The character of the grain of milk powder affects its resistance to oxidation and the appearance of tallowiness chiefly only insofar as it has to do with the relative surface area of the grain. The larger the surface area the greater its possibilities of contact with air and of absorption of oxygen.

The surface area of the grain is determined by the particle size, shape and texture (porosity). Obviously the smaller the particle size of a given shape, the larger the surface in proportion to its cubic content; the more nearly spherical or cubical, the smaller the surface for a given size; and the more porous the texture, the greater the total area of air contact for the same size and shape of grain.

The spray powder grain is usually much finer than the drum powder grain. The particle size of spray powder is approximately .002 inch diameter, while the drum powder is generally ground to pass through a sieve of a fineness of 50 meshes to the inch (diameter .02 inch). However, the spray powder grain is spherical while the drum powder grain lacks definiteness of form, being the product of grinding. Its particles are heterogeneous in form but their general character appears to be of the nature of thin flakes.

The smaller surface of the coarser particle size is offset to some extent by the larger surface provided by its flake-like contour. Because of these facts it is conceivable that there is not a great deal of difference in the exterior surface area of the grain between the two types of powder. The exact results of such comparisons is necessarily influenced by many variables, such as conditions controlling the particle size of the spray powder, as discussed under "Spray-Drying System," and grinding as well as fineness of screen used for sifting the drum-process powder.

However, there is a vast difference in the texture of the powders of the two processes. The spray powder is porous, it carries an air cell in the center which makes it light, fluffy and bulky. There is no air cell in the grain of drum powder. Each grain here is simply a small piece broken off a larger solid unit as the result of grinding. The grain appears to be solid, nonporous, granular and compact.

Because of the difference in texture (porosity) between the grain of the two powders, it appears inevitable that the spray powder, the grain of which contains an air core and is porous, offers far more total surface area to contact with air than does the drum powder with its non-porous grain. Theoretically, therefore, spray powder should be more susceptible to oxidation and tallowiness than drum powder. This has, in fact, been the general experience in commercial manufacture, and is undoubtedly responsible in a large measure for the static condition of manufacture and of commerce in whole milk powders as compared with the tremendous growth in the output of skimmilk powder. However, there has been much improvement in details of manufacture and method of packing whole milk powder within recent years. Much of the spray whole milk powder on the market shows satisfactory resistance to oxidation, it remains free from tallowiness for many months.

Effect of Pre-condensing on Tallowiness.—Whole milk powder made from pre-condensed milk has been found to resist oxidation and the development of tallowiness somewhat better than powders made from uncondensed milk. This applies particularly to spray-powders. This may be due to the fact that the spray powder from uncondensed milk is of smaller particle size and is far more porous, having larger air cells, than the spray powder from pre-condensed milk.

Holm, Greenbank and Deysher,[244] who also found less rapid oxidation in powder made from pre-condensed milk than from uncondensed milk, suggest the possibility that this greater resistance to oxidation may be due to the driving off of acids during the heat treatment preparatory and incident to pre-condensing, thereby eliminating one of the active agencies that is known to intensify oxidation.

Effect of Homogenization on Tallowiness.—The work of Holm, Greenbank and Deysher[244] shows an improvement in resistance to oxidation of milk powder, when made from homogenized milk. Further evidence is needed to definitely determine the reactions involved and to establish the relation of homogenization to oxidation-resistance and keeping quality of dried milk.

Effect of Clarifying on Tallowiness.—Clarifying of milk before drying improves the keeping quality and resistance to oxidation of the resulting powder, as shown by the work of Holm, Greenbank and Deysher.[245] These investigators further found that the improvement is greatest when clarification is accomplished as soon as possible after the milk is drawn. This improvement in keeping quality appears to be due to the removal of the separator slime which may contain metallic and other catalysts. Returning the separator slime to the clarified milk produced no better powder than did the unclarified milk.

These results may explain, as the authors suggest, the reason for the almost unfailing resistance to oxidation of the small amount of fat contained in skimmilk powder. It further lends consistence to the results of Supplee[193] who found cream powders to keep better than whole milk powders, as explained in this chapter under "Effect of Per Cent Fat on Tallowiness." In the case of both skimmilk powder and cream powder, the fat present has had the benefit of clarfication by centrifugal separation, while whole milk powder, unless made from clarified milk, has not been subjected to centrifugal purification.

These findings emphasize the benefits of clarification of milk in the manufacture of milk powder. They suggest the use of the centrifugal clarifier as an effective means of eliminating from the milk agencies that hasten fat oxidation in the milk powder, and of thereby retarding, if not preventing, changes that lead to the development of the objectionable tallowy flavor and odor.

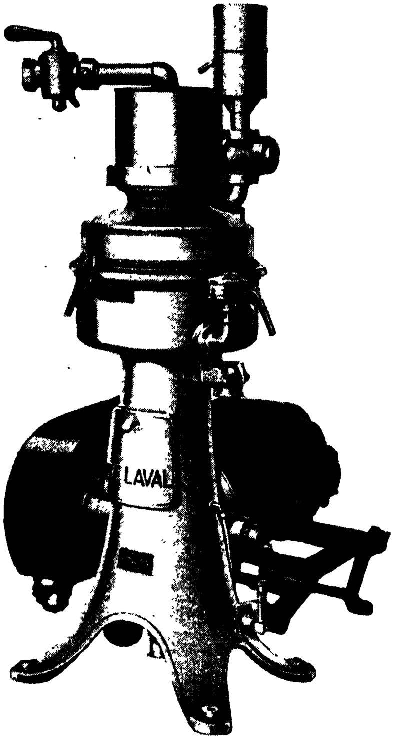

Fig. 140. The DeLaval Clarifier
Courtesy of DeLaval Separator Co.

Effect of Containers on Keeping Quality of Milk Powder.—Other conditions being the same, the more nearly hermetical the package the longer will the milk powder retain its good quality. Optimum keeping quality requires a package that is airtight, moisture-proof and insect-proof. These requirements are indispensable, both for skimmilk powder and for powder containing fat.

The package must be air-tight in order to guard against accelerated oxidation of the fat resulting from exposure to exterior air, and which hastens the development of a tallowy flavor and odor. Air-tightness is necessary also to protect the powder against humid air, which depreciates its solubility, causes lumping, caking and hardening, darkening in color and the development of a stale flavor.

The package must be moisture-proof because of the detrimental effect of moisture on the protein constituents of the milk powder. Milk powder is highly hygroscopic. It takes up moisture readily from the air. According to Supplee[193] the moisture content of skimmilk powders stored in atmospheres of different relative humidities is as follows:

Relative humidity of air.	Per cent moisture in milk powder.
20 to 30%	3.5 to 4.5%
50 to 60%	6.0 to 7.0%
70 to 80%	9.0 to 12.0%

When exposed to humid air the proteins, particularly the casein, swell, harden and their solubility is rapidly destroyed. Simultaneously with this deterioration the powder loses its fresh flavor, develops an objectionable stale flavor and becomes discolored.

The package must be insect-proof because milk powder attracts, and under certain conditions becomes readily infested with diverse insect life, such as ants, termites, maggots, weevil, etc. While such infestation may occur in the factory, it is especially prone to take place in the case of milk shipped to and held in the tropics.

Bulk packages that have been found to offer maximum protection of the powder in transit and in storage in every clime are paraffined, air-tight and moisture-proof barrels or hermetically sealed tin cans. Some of the packages for the retail trade consist of pasteboard containers, others are of special paper composition, such as the "Sealright," still others are tin containers with tightly fitting friction top covers, plain or lacquered, such as the so-called "Doubletite" type cans, and finally there are the hermetically sealed tin cans (tins) similar to those used for condensed milk. These are usually furnished with an additional, loose cover for use after the seal has been broken.

Experimental results by Dahle and Palmer[243] show that milk powder kept very poorly in plain pasteboard containers and but slightly better in the "Sealright" composition paper containers, but that the "Doubletite" tin containers with tightly fitting covers proved far superior to the non-tin containers. Lacquered tin did not improve the keeping quality of the powders, in fact they kept better in plain, unlacquered tin containers.

The latest improvement in retail package is the glass bottle or jar with hermetical seal, in which the powder is packed either under vacuum or in an atmosphere of nitrogen gas. This package has proven highly satisfactory, especially for whole milk and cream powders. It protects the powder against fat oxidation, moisture absorption and protein deterioration and is especially adapted to retail packages lying on the shelves in the store for prolonged periods and under a wide range of temperature conditions.

Effect of Addition of Sucrose on Keeping Quality.—The presence of sucrose in milk powder increases the resistance of the powder against reactions that cause deterioration. Sucrose improves the keeping quality of milk powder. Milk powder made by the film drying process (under vacuum) and containing 13.70 per cent fat and 14.24 per cent sucrose did not show the slightest manifestation of tallowiness when kept by the author for three years in a tin container, the seal of which had been broken. The powder was held at room temperature.

Likewise this powder remained remarkably free from the characteristic stale flavor of old milk powder. It did not lump, nor harden and its color remained normal. The grain of this powder was very coarse, approximately of the fineness of granulated cane sugar. Its physical stability under prolonged exposure to air of varying humidities suggested that it was far less hygroscopic than milk powder containing no sucrose.

Its freedom from tallowiness suggests that the fat globules were coated with a film of sucrose that protected the fat against the oxidizing action of the air and other agents that cause or accelerate oxidation leading to a tallowy condition. Its freedom from staleness indicates that the casein was probably similarly protected by the sugar.

CHAPTER XXXIII

MARKETS

Markets of Dried Milk.—Dried milk is intended for all the purposes for which fluid milk is used. The purpose of drying milk and milk products is to preserve the valuable food elements they contain in as nearly an unchanged and natural condition as possible, and to make them available, at all times of the year and in all parts of the world, at minimum cost of transportation and storage and without damaging deterioration.

It is to equalize supply and demand, and hold over the surplus from the time of large supply and low prices to the time of shortage and high prices. It is to supply milk and milk products to those countries and territories where geographical or climatic conditions are not suited to the profitable husbandry of the dairy cow, and where these products in their original fluid form are not available, or where obstacles of transportation preclude their use, as is the case in the tropics, the arctic regions, mining and lumber camps, the army and navy, transcontinental and transoceanic traffic. It is also to preserve the food elements in the valuable by-products, such as skimmilk, buttermilk and whey and to make them available in concentrated form to diverse prepared-food manufacturing plants, bakeries, ice cream factories, and to mixed feed mills at times and in localities that render their supply in their original bulky form inaccessible. It is, in short, to better economize, to more efficiently utilize and to more widely distribute the product of the dairy cow, so as to increase her returns and make both production and manufacture more profitable.

Uses of Whole Milk Powder.—The markets for dried milks containing milk fat, such as whole milk powder, cream powder and part skimmilk powder, appear to have been limited in the past, and the volume of production of whole milk powder and cream powder in the United States, barring temporary fluctuations, has not shown any consistent increase during the last 10 to 15 years, while the production and sale of skimmilk powder has enjoyed a tremendous growth, its annual output having quadrupled during the past decade. This static situation of the volume of production of powdered whole milk is in good part due to the uncertain keeping quality of this product and in part to trade-retarding competitive practices.

Improvements in manufacture and packing, made within recent years, promise more dependable resistance to age deterioration of powdered whole milk. The more general use of the centrifugal clarifier for the fluid milk as soon as it arrives at the factory and closer attention to prompt and proper cooling of the powder after drying and before packing, alone are destined to materially retard age-deterioration and to greatly improve the possibilities of whole milk powder as an important commodity of the world market.

The improved quality has in fact already increased the demand for dried whole milk. This is only the beginning of what may be expected to develop into a stampede of user-demand from powdered skimmilk to powdered whole milk. There is no channel of utilization of powdered skimmilk, for direct human consumption or for the preparation of human food, in which powdered whole milk would not serve the purpose fully as well as, and in most cases even better than, powdered skimmilk, provided that it has dependable keeping quality.

The improved quality will continue to stimulate the use of whole milk powder for direct consumption in the form of reconstituted milk, and in the manufacture of diverse prepared foods. The medical profession is recognizing the superiority of powdered whole milk over any other form of milk, fresh or concentrated, as a substitute for fluid milk or a supplement to the diet, for use as infant food and in hospitals and sanitariums, particularly in tropical countries and other regions where whole milk of good quality is scarce or not available at all. Large quantities of dried whole milk are absorbed also in the manufacture of milk chocolate, the milk fat being one of the essential components upon which milk chocolate depends for its smoothness of texture and superior flavor. There appears no good reason, likewise, why powdered whole milk of dependable keeping quality would not supply the needed milk solids plus milk fat fully as economically and more advantageously than powdered skimmilk now does in bread baking, in bakers' sweet goods, in the manufacture of ice cream and for most other prepared foods containing milk solids and milk fat, and intended for human consumption.

Uses of Dried Skimmilk.—By far the largest portion of the total output of dried milk products is dried skimmilk. It is especially such valuable by-products of milk as skimmilk, the more efficient utilization of which is made possible by the process of drying. The manufacture of butter in the United States provides annually some 18,800,000,000 pounds of skimmilk. This skimmilk, if manufactured into dried milk, would yield approximately 1,880,000,000 pounds of skimmilk powder. Much of this enormous supply of skimmilk is not used efficiently or is wasted. In the form of skimmilk powder large quantities could be turned into channels of human consumption, thereby stopping a now existing wasteful leak in the dairy industry and supplying the human family with a much needed and most valuable food product.

The superior quality of the skimmilk powder that is now manufactured by the use of the improved methods of manufacture, handling and packing, has opened channels of the most diversified uses of dried skimmilk for human consumption. This, together with the rapidly increasing knowledge of the consuming public and the manufacturer of food products, as to its cheapness, wholesomeness, and food value, has resulted in many new uses and has vastly increased the demand for this product in the markets already established.

Dried Skimmilk in Baker's Bread.—The baker has found the use of dried milk to the extent of about six pounds of dried skimmilk for every 100 pounds of flour to be a most advantageous practice. The use of dried milk adds valuable milk solids to the bread. It supplements the nutritive elements of wheat flour by such high-quality milk solids as the readily digestible, muscle-building milk protein, by the health-promoting and energy-building milk sugar, and by the invaluable lime, phosphorus, and other minerals contained in milk, that promote the growth of a healthy bony structure and sound teeth. It also increases the vitamin content of the bread.

But aside from actually making the bread more nutritious, more wholesome, and a more completely balanced food, dry milk, when added to the flour at the rate of about 6% increases the weight of the loaf 6% and the size of the loaf about 12 to

15%. It augments the waterholding and retaining ability of the loaf, and therefore, keeps the loaf fresh longer. It improves the appearance and palatability of the loaf, thus stimulating consumption. These advantages are accomplished at practically no additional cost, because there is enough extra loaf per barrel of flour to pay for the cost of the dried milk. The fact that the simplest, safest, and most effective way to improve the quality of bread lies in incorporating milk solids in its composition, promises the "Staff of Life"—bread—to play, as milk bread, even a more important role in the diet of the human family in the future than it has in the past and to demand and absorb an increasingly large portion of the dried milk output of the country.

It is estimated that the baker in the United States consumes approximately 35,000,000 barrels of flour in bread-making per year. The net weight of a barrel of flour is 196 pounds. At six pounds of dried skimmilk per 100 pounds of flour the baking industry alone would furnish a market for about 411,000,000 pounds of skimmilk powder annually. This amount is nearly 150,000,000 pounds in excess of the total output of dried skimmilk recorded for the year 1932. See also "Federal Standard for Milk Bread."

Federal Standard for Milk Bread.—The composition of bread permissible to be offered for sale in interstate commerce in the United States as "Milk Bread," is defined by and must comply with the Federal Standard for "Milk Bread," as explained by Pirrie.[250] This standard requires milk bread to contain a certain proportion of both milk fat and milk solids not fat.

The Federal Standard is based on an average normal water absorption of the wheat flour of 60 pounds of water per 100 pounds of flour. The total milk solids required by the standard are based on this same water absorption ratio of the flour. Thus, in the case of using whole milk, enough of the milk must be used to have the water contained in the milk represent 60 pounds per 100 pounds of flour. On the basis of standard whole milk containing 3.5 per cent fat and 8.5 per cent solids not fat, the milk contains $100 - 12 = 88$ per cent water. The amount of milk that is needed, in order to add 60 pounds of water per 100 pounds of flour is, therefore, $\frac{100 \times 60}{88} = 68.18$ pounds of liquid whole milk.

This is the weight of milk of the above percentage composition of milk fat and solids not fat, that contains 60 pounds of water.

The 68.18 pounds of whole milk thus contain $\frac{68.18 \times 12}{100} =$ 8.18 pounds of total milk solids. This then represents the total milk solids that must be added per 100 pounds of wheat flour in order to comply with the Federal Standard for milk bread.

When using dried whole milk, therefore, an amount of milk powder must be used per 100 pounds of wheat flour, that contains not less than 8.18 pounds of total milk solids. The whole milk powder needed is calculated on the basis of 3.5 per cent moisture content in the milk powder; hence $\frac{8.18 \times 100}{96.5} = 8.48$ pounds is the amount of whole milk powder needed to provide the 8.18 pounds of total milk solids required per 100 pounds of wheat flour in standard milk bread.

In case skimmilk powder is used, the fat may be provided by supplementing the milk powder with butter. In this case the calculations are based again on 3.5 per cent moisture in the milk powder and on 20 per cent moisture in the butter.

On the basis of the standard composition of whole milk, i. e., 8.5 per cent solids not fat and 3.5 per cent fat, the amount of solids not fat and of fat required in the form of skimmilk powder and butter respectively, are:

$$\frac{68.18 \times 8.5}{100} = 5.79 \text{ pounds solids not fat}$$

$$\frac{68.18 \times 3.5}{100} = 2.39 \text{ pounds fat}$$

$$\text{Total} = 8.18 \text{ pounds total milk solids.}$$

In order to provide the above amounts of solids not fat and of fat, the amounts of skimmilk powder and butter are:

$$\frac{5.79 \times 100}{96.5} = 6 \text{ pounds of skimmilk powder}$$

$$\frac{2.39 \times 100}{80} = 3 \text{ pounds butter}$$

The formulas for standard milk bread made by the use of whole milk powder, and of skimmilk powder and butter, respectively, are:

Dough made with Dried Whole Milk

Flour	100 Pounds
Dried Whole Milk	8 lbs. 8 oz.
Water	As needed for dough

(Plus other usual ingredients)

Dough made with Dried Skimmilk and Butter

Flour	100 lbs.
Dried Skimmilk	6 lbs.
Butter	3 lbs.
Water	As needed for dough

(Plus other usual ingredients)

The Federal Standard applies to all milk bread intended for "interstate" commerce. Some states have standards for milk bread that are at variance with the Federal Standard. For "intra-state" commerce, therefore, the formula must be adjusted to comply with the respective State Standard.

Dried Skimmilk in Baker's Sweet Goods.—The use of dried skimmilk in the baking industry is not confined to bread only. Dried skimmilk lends itself admirably as a component of cakes, wafers, biscuits, doughnuts, fried cakes, pie fillings, waffles, pancakes, and the like. Dried skimmilk in the make-up of prepared flours used for these purposes by the baker, or in the home kitchen, greatly adds to the safety, nutritive properties, and wholesomeness of this great variety of fancy baker's goods and improves their flavor, texture, and appearance.

Dried Skimmilk in Ice Cream.—The future development and success of the ice cream business largely depend on the quality of the ice cream. About two-thirds of the solids in ice cream are milk solids. It is indispensable that these milk solids be provided in the form of fresh sweet dairy products, for on their superior quality depends the quality of the ice cream.

For this purpose the use of fresh and sweet milk and cream is most desirable. However, the difficulty of insuring a supply of fluid milk products of high quality, adequate and flexible enough to take care of the widely varying seasonal requirements of the ice cream factory, is obvious to every experienced ice cream maker. The availability of dried skimmilk offers a practical means for the satisfactory solution of this problem. Dried skimmilk and sweet butter of good quality supply a complete assortment of milk solids necessary for the mix.

Dry skimmilk is becoming increasingly recognized as one of the most convenient and most suitable forms of milk solids for use in ice cream. It is already utilized in large quantities for this purpose and the tremendous growth of the annual output of ice cream assures an increasingly large demand for high grade skimmilk powder for use by the ice cream industry. The total production of ice cream in the United States for the year 1931 was estimated to be 300,000,000 gallons. Standard ice cream contains approximately 10 per cent milk solids not fat. If one-half of the milk solids not fat contained in this volume of ice cream were supplied in the form of dried skimmilk, the ice cream industry would require approximately 125,000,000 pounds of dried skimmilk annually.

Dried Skimmilk in Other Food Products.—Skimmilk powder is further advantageously used in the consumers' kitchen, in candy and confectioners' establishments, in the manufacture of starter for cream ripening, of cultured buttermilk, of cottage cheese and cream cheese, in the composition of diverse prepared food products, such as cereals, soups, noodles, and sausages. The chocolate factories absorb vast quantities of dried skimmilk, and it is extensively used in the preparation of choice toilet soaps and a variety of cosmetics.

Dried Skimmilk for Infant Feeding.—Similarly as in the case of dried whole milk, so has the use of dried skimmilk been found of the greatest value in the diet of infants and children in the absence of fluid milk. It has proven especially valuable and suitable as a basic constituent in prepared infant foods. The value of skimmilk powder for these purposes is further augmented by its splendid keeping quality. Its deficiency in milk fat may be readily taken care of by the addition to the diet of butterfat in the form of fresh or evaporated cream, butter, or pure butter oil, or cod liver oil.

Dried Skimmilk for Animal Feeding Purposes.—There is no substitute for milk. The necessity of milk solids for the feeding of the young holds good in the raising of calves, pigs, and chicks, as well as in the nourishment of babies and growing children. While the most profitable channels of marketing dried skimmilk lie in the food supply for the human family, the supplementing of the feed ration for young stock and poultry has in many cases been found economical and profitable. The preparation of stock feed thus provides an additional market for any surplus of dried skimmilk, not absorbed through the manifold channels of human consumption.

Table 54.—United States Imports and Exports of Dried Milk

Year	Exports	Imports	Net Exports
	Pounds	Pounds	Pounds
1925	5,622,000	2,988,000	+ 2,634,000
1926	3,269,000	6,136,000	– 2,867,000
1927	3,007,000	4,010,000	– 1,003,000
1928	3,288,000	7,394,000	– 4,106,000
1929	5,063,000	4,159,000	+ 904,000
1930	6,223,000	3,145,000	+ 3,078,000
1931	12,790,000	360,000	+12,430,000
1932	3,577,000	583,000	+ 2,994,000

CHAPTER XXXIV

DRIED BUTTERMILK AND DRIED WHEY

DRIED BUTTERMILK

Definition.—Dried buttermilk, or buttermilk powder, is the product resulting from the condensing of creamery buttermilk to a state of relative dryness. It usually contains from about 4 to 7.5 per cent of water.

History of Buttermilk Drying.—The drying of buttermilk as a commercial industry is essentially a child of the World War. Small quantities of dried buttermilk were made and used in mixed feeds for poultry a little over a score of years ago. It was, however, the feed shortage and the high prices of all farm products caused by the ravages of the World War that emphasized the possibilities and the value of preserving such valuable dairy by-products as buttermilk and that developed the manufacture of dried buttermilk into an important branch of the dairy industry.

Increase in Annual Production of Dried Buttermilk Phenomenal.—The following table may serve to show the phenomenal growth of the dried buttermilk industry. From the modest beginning of 342,485 pounds in 1916, its output increased with leaps and bounds, until in 1930 U. S. Government statistics show an output of over 64 million pounds for that year. While the annual production of fluid buttermilk doubled in volume from 1916 to 1930, the proportion of the total fluid buttermilk that was utilized in the manufacture of dried buttermilk increased from less than one-half per cent in 1916 to 31.7 per cent in 1930. Over one-third of all the buttermilk produced in American creameries was thus absorbed in the manufacture of dried buttermilk in 1930.

Methods of Manufacture.—Dried buttermilk has been commercially manufactured by the spray-drying system and by the atmospheric and vacuum drum-drying processes. Today, however, buttermilk is almost exclusively dried by the use of the atmospheric drum dryer.

The important question of effect of heat treatment on solubility or suspension stability is not involved here. Fluid buttermilk itself is a physically unstable suspension of relatively coarse, insoluble curd. Buttermilk powder, upon reconstitution, therefore, shows similar insolubility and instability of suspension, regardless of process of manufacture. There is nothing gained by using solubility-preserving processes of drying with a product which in its original fluid state lacks protein solubility. The spray-drying process is mechanically not well suited for desiccating buttermilk because of the tendency of clogging the spray nozzles.

Table 55.—Annual Production of Dried Buttermilk and Amount of Fluid Buttermilk Absorbed in Its Manufacture in the United States

Year	Dried Buttermilk Made	Fluid Buttermilk		
		Total Production of Fluid Buttermilk[1]	Fluid Buttermilk Utilized in Manufacture of Dried Buttermilk[2]	Per Cent of Total Fluid Buttermilk Utilized in Manufacture of Dried Buttermilk
	Pounds	Pounds	Pounds	Per Cent
1916	342,485	1,140,000,000	4,029,235	.35
1917	2,557,228	1,139,000,000	30,085,035	2.64
1918	4,341,157	1,189,927,500	51,072,435	4.28
1919	5,278,827	1,477,500,000	62,103,847	4.41
1920	5,585,906	1,295,365,500	65,775,364	5.08
1921	7,708,384	1,582,407,000	90,686,870	5.73
1922	9,007,000	1,730,272,500	105,964,705	6.12
1923	13,032,000	1,878,321,000	153,317,647	8.16
1924	18,058,000	2,034,120,000	212,447,059	10.44
1925	22,772,000	2,042,289,000	267,905,882	13.11
1926	31,378,000	2,177,649,000	369,152,941	16.95
1927	38,435,000	2,244,706,500	452,176,470	20.14
1928	45,502,000	2,230,573,500	535,317,647	24.08
1929	54,215,000	2,395,540,500	637,823,529	26.62
1930	64,601,000	2,392,846,500	760,011,764	31.76
1931	50,535,000	2,501,178,000	594,529,411	23.77
1932	48,712,000	2,642,846,000	573,082,000	21.68

[1] Based on 1.56 lbs. buttermilk per lb. of butter made.
[2] Based on a yield of 8.5 lbs. dried buttermilk per 100 lbs. of fluid buttermilk.

The additional fact that the great bulk of all dried buttermilk is intended and used for hog and poultry feeding purposes renders the matter of solubility and freedom of cooked flavor unimportant and emphasizes the controlling importance of economy of manufacture. For these reasons the atmospheric drum dryer, with its much lower initial cost of installation and its simplicity and economy of operation, is given preference over all other systems and processes for drying buttermilk.

Drying Fluid or Pre-Condensed Buttermilk.—Buttermilk may be dried with or without pre-condensing. Large volumes of buttermilk in the United States are dried without pre-condensing under the Collis Patent.

The Collis Buttermilk Dryer.—This dryer and process are covered by U. S. patents numbers 1,317,777 (1919) and 1,356,340 (1920), granted to N. P. Collis, St. Paul, Minn. The Collis buttermilk dryer is a single drum unit. Its special features consist of a spray pipe with pump and supply tank and a battery of buttermilk storage tanks so connected with a pump as to provide continuous agitation of the buttermilk.

Special emphasis is placed on delivering the buttermilk in a thoroughly mixed and finely divided state to the drum surface. This requires suitable means to keep the buttermilk supply cool and vigorously agitated until it impinges upon the drying drum. To this end the buttermilk is kept in tanks, usually concrete tanks installed in the coolest part of the plant, preferably the basement, and keeping it in continuous circulation by means of a pump.

This same pump also serves the supply pan which is located underneath the drying drum. From the supply pan another pump sprays the buttermilk against the revolving drum surface while simultaneously maintaining a constant circulation of the liquid through the spray pipe, overflow pipe and back to the supply pan. This circulation is continued as long as there is any liquid in the supply pan.

The spray is directed tangentially against the under side of the drum and in the same direction as the revolution of the drum, thus aiding the liquid to adhere to the drum surface. A considerable portion of the milk falls back into the supply pan and in this manner helps to agitate the liquid in the pan and to forewarm it, making possible the maintenance of a temperature of about 150 to 160°F.

The roll revolves at about two R.P.M. The film of buttermilk reaches a temperature of approximately 200°F. by the time it approaches the scraper (in 30 seconds), when it is sufficiently dry to be scraped off. At this point the moisture content of the dried film is approximately 10 to 15 per cent. From the scraper the dried product falls into a "cut flight" conveyor which moves it toward one end of the machine and drops it into another conveyor on which it travels to a dried milk receptacle. In its journey from drying drum to dried milk receptacle the scraped-off film cools, disintegrates somewhat and surrenders the remainder of its removable moisture, reducing the moisture content to about five per cent, and after the lactose in it is completely crystallized the product is ready for milling. It is then packed in sacks or barrels or tin containers.

Film-Drying Pre-Condensed Buttermilk.—When drying the uncondensed buttermilk, the film that adheres to the drum surface is relatively thin and the evaporative duty of the dryer is relatively high, greatly limiting the capacity of the drying unit. It has therefore been found advantageous and economical to pre-condense the buttermilk to a concentration of approximately 4 to 1.

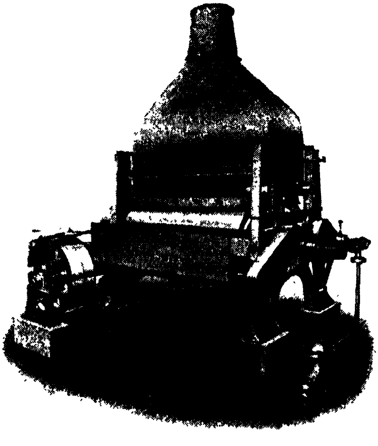

Fig. 141. Buttermilk Dryer
Courtesy of Silkeborg Maskinfabrik

Pre-condensing has the further advantage of stabilizing the emulsion, making unnecessary the special precautions of continuous circulation while between supply pan and drum surface, and making possible the satisfactory use of the double drum unit of the Just-Hatmaker type of dryer.

The practice of pre-condensing the buttermilk is gaining in favor and in usage. The pre-condensing is done either in the vacuum pan or by the atmospheric "Continuous Concentrator," or by similar equipment, as explained in Chapter XIX. It has been found advantageous in such cases to so coordinate the rate of pre-condensing and drying as to reduce the two processes to one continuous operation, thereby obviating the need of intermediate holding equipment, minimizing loss due to spillage and economizing time, labor and fuel.

Preparation of Dried Buttermilk for Market.—The dried product, as it comes from the dryer, consists of shreds and thin sheets. In order to convert it into mechanically suitable condition for packing and marketing, it is conveyed to the grinder and bolter, where it is reduced to a uniform, granular meal, similar to corn meal. It is now ready to be packed into sacks, barrels or tin containers.

Yield of Dried Buttermilk.—The yield of dried buttermilk per 100 pounds of fluid buttermilk depends largely on the per cent solids in the original buttermilk and on the per cent moisture in the finished product. Normal buttermilk that has not been diluted with water before it reaches the drying plant contains approximately 9 per cent solids and the dried buttermilk averages from 5 to 10 per cent moisture. It is possible, therefore, to secure a yield of from 9.5 to 10 pounds of dried buttermilk per 100 pounds of normal buttermilk.

In commercial manufacture, however, this high yield is seldom obtained, largely because the per cent solids in the majority of the creamery buttermilk is considerably lower, due to more or less unavoidable admixture of water to the cream between the farmer's can and the churn, as explained in detail under "Condensed Buttermilk," Chapter XVIII.

In exceptional cases buttermilk has been found to contain as little as 6.5 per cent solids. Ordinarily, and with the average quality of buttermilk received, the yield averages about 8¼ to 8¾ lbs. of dried buttermilk per 100 pounds of fluid buttermilk.

Composition of Dried Buttermilk.—The composition of dried buttermilk is controlled chiefly by the composition of the fluid buttermilk and the completeness of the removal of the moisture. Nothing except water is removed and nothing is added to the buttermilk in the manufacture of dried buttermilk. The two products differ from one another only in their degree of concentration. In the case a neutralizer such as lime hydrate, or sodium carbonate, or bicarbonate, is used in the creamery to standardize the cream for acidity, the ash content of both the fluid and the dried buttermilk is slightly higher than it is in buttermilk from unneutralized cream. The following analyses indicate the percentage composition of both fluid buttermilk and dried buttermilk:

Table 56.—Composition of Fluid and Dried Buttermilk

	Average Normal Buttermilk	Average Creamery Buttermilk	Dried Creamery Buttermilk Individual Samples		
			A	B	C
	%	%	%	%	%
Water	90.50	92.00	7.50	6.00	9.25
Fat	.50	.50	6.50	7.23	3.40
Protein	3.60	3.10	36.24	36.10	33.50
Milk sugar	3.90	2.90	35.50	35.28	40.55
Lactic acid	.60	.65	6.00	6.70	4.95
Ash	.75	.85	8.25	8.69	8.35
Total solids	9.35	8.00	92.49	94.00	90.75

Keeping Quality of Dried Buttermilk.—Dried buttermilk, manufactured properly, has excellent keeping quality. Its low moisture content and relatively high acidity which, as shown in the above analyses, averages 5 per cent or better, act as effective preservatives. It has a tendency to absorb moisture from the air, however, in a manner similar to other dried milk products.

The package, therefore, must be protected against excessive exposure to air, otherwise it will become damp and lumpy with age. Because of its high acid content, dried buttermilk keeps better and is less prone to become stale and moldy than dried skimmilk kept under the same conditions of package and storage.

Digestibility of Dried Buttermilk.—Accurate data on the relative digestibility of dried and fluid buttermilk appear to be lacking, but the experience of feeders indicates that the digestibility of the buttermilk is not impaired by the drying process. These observations are further confirmed by a limited number of digestibility tests made in the laboratory. These tests show that the digestibility of dried buttermilk, made by atmospheric film drying, is equal to that of the fluid buttermilk.

Uses of Dried Buttermilk.—Limited amounts of dried buttermilk are sold to bakeries and to factories that manufacture prepared foods. The great bulk of the dried buttermilk output goes to stock feed mills and to feeders of pigs, hogs, poultry and laying hens.

It use for feeding purposes has demonstrated its great value as a stock feed. Its food nutrients are of the highest quality, it is relished and readily digested, its high acid content acts as a tonic, and assist in keeping animals and fowls in healthy condition. It accelerates the power of assimilation of other feeds in the ration, thereby augmenting their digestibility and their economy as feeds and giving the animal greater capacity for the consumption of feed and water. Heuser[248] reports: "We have used the skimmilk powder and the buttermilk powder for laying hens and for chick feeding, but not for fattening. In both the case of the young and mature stock, we have obtained better results from the buttermilk product.

Dried Whey.—Dried whey or whey powder may be desiccated by the use of any process suitable for the drying of milk.

Its chief value lies in its usefulness in the diet of infants and invalids, with whom the consumption of casein produces digestive disturbances. Since fresh whey is often not obtainable, the whey powder, the good keeping quality of which permits of keeping it on hand, furnishes an admirable substitute. When made from sour whey, it offers many advantages in cooking and baking and should be especially well suited for such dishes as pan cakes, etc.

Dried whey has also found extensive use as an important component of modified milk preparations for infant feeding. For certain preparations of this nature preference has been given to lactose-free whey powder. This is prepared from perfectly sweet whey, such as whey from Swiss cheese factories. The whey is condensed to a high degree of concentration and the milk sugar is precipitated by crystallization at low temperature. The condensed whey, from which the lactose has been removed, is then dried, preferably by the spray-drying system.

CHAPTER XXXV

MALTED MILK

Definition.—The prepared food known as malted milk is the product made by combining whole milk with the liquid separated from a mash of ground barley malt and wheat flour in such a manner as to secure full enzymic action of the malt extract, and reducing the mixture to dryness by desiccation. It may also contain added sodium chloride, sodium bicarbonate and potassium bicarbonate. The U. S. Federal standard provides that malted milk shall contain not less than 7.5 per cent milk fat and not more than 3.5 per cent moisture. Malted milk differs from other malted food products, such as Liebig's Food, Mellin's Food and Horlick's Food, in that it contains milk while the latter contain no milk. Each pound of malted milk contains the total solids of approximately 2.2 pounds of whole milk.

History of Malted Milk Industry.—The process of the manufacture of malted milk was invented by Mr. William Horlick, of Racine, Wis., in the year 1883. The product was first placed on the market under the name of "Malted Milk," given it by its inventor, in 1887.

Prior to the advent of Horlick's malted milk Mr. Horlick was making "Horlick's Food." It was through suggestions of members of the medical profession, who complained that it was almost impossible to obtain first class, pure, clean, wholesome, whole milk, that Mr. Horlick took up the idea of malted milk. In consultation with Dr. R. C. Hindley, then Professor of Chemistry at the Racine College, who later became Chief Chemist and Superintendent for Mr. Horlick, the manufacture of malted milk was subjected to considerable experimenting by its inventor before the product reached the market in perfected form.[251, 252]

The convenience, nutritive value and digestibility of this product attracted favorable attention on the part of the medical profession, and its relishing properties appealed to the public. The industry grew rapidly; its prosperity attracted other manufacturers of dairy products, so that today malted milk is made by numerous firms and the annual output is assuming large proportions, as shown in Table 57.

Table 57.—Annual Production of Malted Milk in the United States

Year	Annual Output of Malted Milk Pounds	Year	Annual Output of Malted Milk Pounds
1916	11,654,000	1925	18,050,000
1917	13,852,000	1926	20,673,000
1918	15,623,000	1927	22,116,000
1919	17,436,000	1928	21,128,000
1920	19,725,000	1929	22,850,100
1921	15,651,750	1930	22,691,000
1922	13,659,000	1931	19,197,000
1923	15,331,000	1932	13,215,000
1924	15,899,000		

Manufacture of Malted Milk.—The manufacture of malted milk divides itself chiefly into two phases, namely first, the malting of barley which has to do with the cleaning, steeping, germinating of the barley, and the drying of the barley malt, and second, the manufacture proper which consists of preparation of the mash of barley malt and wheat flour, conversion of the starch into maltose and dextrin by enzymic action, separation of the hulls from the barley malt mix, addition of whole milk or whole condensed milk, condensing, drying, grinding and packing ready for the market.[253]

Malting the Barley.—The purpose of malting is to produce a sufficient quantity of diastatic enzymes (enzymes capable of converting starch into sugars and intermediate products) to completely and rapidly convert the starch of the grains (the wheat and barley flour) into soluble, easily digested and readily assimilated maltose and dextrin. For this purpose the wheat grain itself could be malted, but barley malt is used because of its pleasant and agreeable flavor, characteristic of the flavor and aroma of barley malt.

General Discussion of Malting Barley.—Longitudinally the small grain, in this case the barley grain, divides itself into the germ at the lower end and the endosperm consisting chiefly of starch cells which are surrounded by the testa which in turn is covered by the bran and husk. The germ is separated from the starchy portion of the kernel by a membrane of cellulose. When the barley grain is allowed to become moist and held at temperatures between 50 and 75°F., it begins to germinate. This results in the development of an acrospire or sprout, which grows upward from the germ under the husk until it breaks through the tip of the kernel where it appears as the first leaf or stem. At the same time fine rootlets grow downward from the germ to later feed the young plant from the soil after the nourishment contained in the kernel is exhausted.

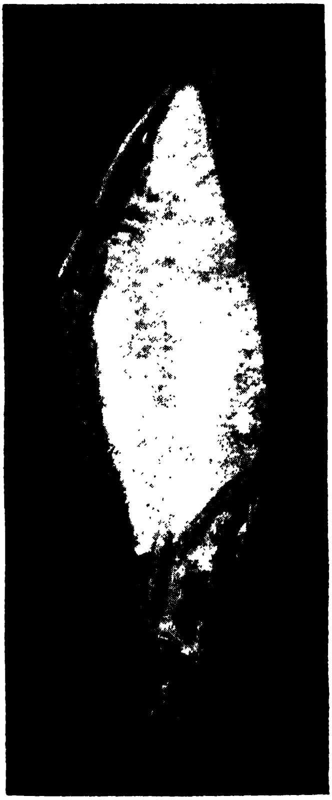

Fig. 142. Original barley grain

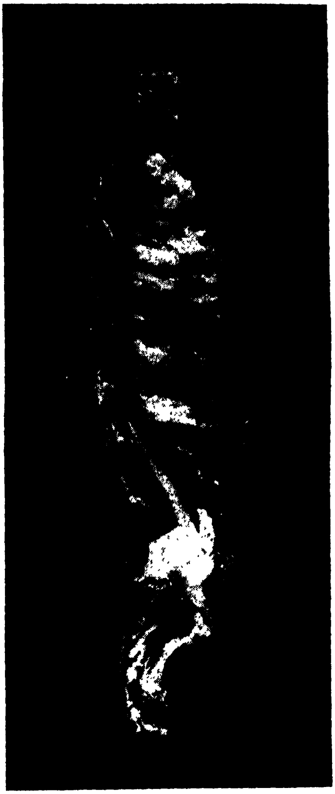

Fig. 143. Barley grain after malting, showing acrospire

Microphotographs, mag. X 15

Simultaneously with the early stages of germination, enzymes are produced that assist in converting the nitrogenous and starchy material into readily available plant food for the growing grain. Thus protein enzymes, such as peptases, are formed which attack the proteids converting them into simpler and more soluble compounds, such as albumoses, peptones and amides. Starch enzymes, such as diastases are produced which convert the starch into dextrins and maltose. Cellulose-dissolving enzymes, such as cytase or cellulase are formed, dissolving the cell wall between the germ and the endosperm of the kernel, thereby enabling the diastase to diffuse through the starch.

In the case of the malted milk the chief purpose of germinating the barley grain is to develop in it a high diastatic value, so as to make possible rapid and complete conversion of the starch in the mixture of barley malt and wheat flour to readily assimilable dextrin and maltose later during the mashing process. Experience in malting has shown that when the germinating process has progressed to the point where the acrospire has grown to about three-quarters of the length of the barley kernel and the endosperm has become mellow, sufficient diastase has developed to accomplish this. Carrying the germination farther or to the point where the acrospire emerges from the tip of the grain is not desirable, as such growth causes excessive and unnecessary destruction of the starch and protein. Germination is, therefore, checked when examination of the barley kernel reveals an acrospire of a length of three-quarters that of the grain. This is done by drying the "green" barley malt in a kiln.

Selection and Cleaning of Barley.—For best results the very highest grade of barley only is suitable. The barley must be mellow so as to respond satisfactorily to the processes of steeping and germination. Barley kernels that lack uniformity of hardness throughout their structure do not steep uniformly and refuse to sprout vigorously. Such kernels are termed "glassy" or "steely," their interior showing a bluish or greenish tinge. Barley kernels that are glassy instead of mellow do not yield a high quality of barley malt.

The barley, though purchased clean, is preferably subjected to a thorough screening to free it from foreign seeds, broken kernels, dirt and other impurities and imperfections.

Steeping the Barley Grain.—The cleaned barley grain is first subjected to the steeping process. The steeping consists of soaking the kernels in water until the water has completely penetrated them. For this purpose tanks are used, in which it is wetted down with enough water to be completely submerged, the water standing one to two feet deep above the grain. The water has a temperature of about 68°F. The water is changed at intervals of about eight hours, so as not to become sour or stale. The steeping occupies from 24 to 48 hours. The frequency of changing the water and the duration of steeping vary somewhat with malt house and season of year. Some of the steep tanks in use hold about 500 bushels of barley.

These steep tanks are cylindrical and taper toward their bottom. The bottom is equipped with a screened water outlet and a gate for dropping the grain into a chute leading to the germinating floor below.

During the steeping process the barley kernel swells considerably, taking up much water so that it now contains approximately 45 to 50 per cent of moisture. Some grains, consisting mainly of oats and inferior barley kernels, generally rise to and float on the surface of the water of the steep tank. These floaters are skimmed off, dried separately and sold as feed.

Germination of Barley.—There are three systems of handling the steeped barley grain during the germinating process. The wet grain is either spread out on a plain floor (cement or tile floor), or it is placed in long bins with perforated bottoms (Saladin or pneumatic trough system), or it is placed in horizontally revolving drums (Pneumatic drum system).

In each system control of moisture and temperature is important. These two factors determine the extent to which diastase and other enzymes develop. The desired moisture is provided by sprinkling water on the germinating grain and the temperature is controlled by the depth of the barley mass and by agitation and air circulation.

In the case of the pneumatic drum system the stirring is accomplished by the slow, continuous or intermittent rotation of the drums containing the germinating barley. The ends of the drums are connected with air ducts through which moistened and properly tempered air is blown through the grain; a perforated conduit running lengthwise through the center of the drums carries the spent air to the outside.

In the Saladin system the barley lies on the perforated false floor of the bins. The grain is spread out over the entire floor of each bin to a depth of about two feet. These bins are about 50 to 60 feet long and 10 to 15 feet wide. The layer of barley is plowed up at intervals by mechanical turners or revolving helices and sprinkled with water when necessary. Cool moistened air is drawn down through the grain and out through the perforated floor, thus permitting fresh air to reach the whole mass of grain. The circulation of the air is facilitated by the presence of an air pit about three feet deep below the perforated floor.

Where the germinating process is done on a plain floor, the barley is spread out to a variable depth ranging from 4 to 14 inches, a depth of about 7 to 8 inches having been found satisfactory. Water is sprinkled over the grain and the grain is periodically turned or raked either by hand tools or by mechanical turners.

As the germinating grain generates heat the depth of the layer of barley on the floor is an important factor in controlling the temperature of the barley. The heat hastens the germinating process. Both temperature and moisture must be closely watched in order to insure the proper speed of germination and to produce barley malt with high diastase value without excessive destruction of starch. The turning and exposure to air assists in preventing matting of the grains and in checking the growth of rootlets.

The germinating process occupies from 5 to 7 days. In order to properly germinate the barley in 5 days a temperature of about 75°F. is maintained in the barley mass. This requires a temperature of the circulating air of about 60 to 65°F. This is further facilitated by saturating the air with moisture and sprinkling the grain with water when needed. The beginning of the germinating period is often spoken of as the coutching. This is to allow the grain to warm up to the proper germinating temperature. During the coutching no water is added. The successful germinating process depends largely on the judgment of the maltster who decides, from the length and appearance of the acrospires, and the mellowness of the grain center, when the production of diastase has been carried to the right point. The barley, when properly germinated, should contain a pure white starch center and the acrospire should be about three-quarters of the length of the kernel. The kernels should be mellow. Fine rootlets are present at the germ end or base of each kernel at this stage.

The germinating floors or perforated drums are cleaned when empty by forcing water under pressure through the perforations. In floor malting the floors must be kept clean by scrubbing.

Kilning or Drying the Barley Malt.—The germinated barley is now transferred to the kiln for drying and arresting further germination. The kiln consists of a vault with fire box or furnace at bottom, one or more grated or wire floors and roof (usually of pyramidal shape) with outlet and adjustable doors for exit of vapors. The removal of vapors is generally accelerated by suction fans placed at the air outlets. In the case of

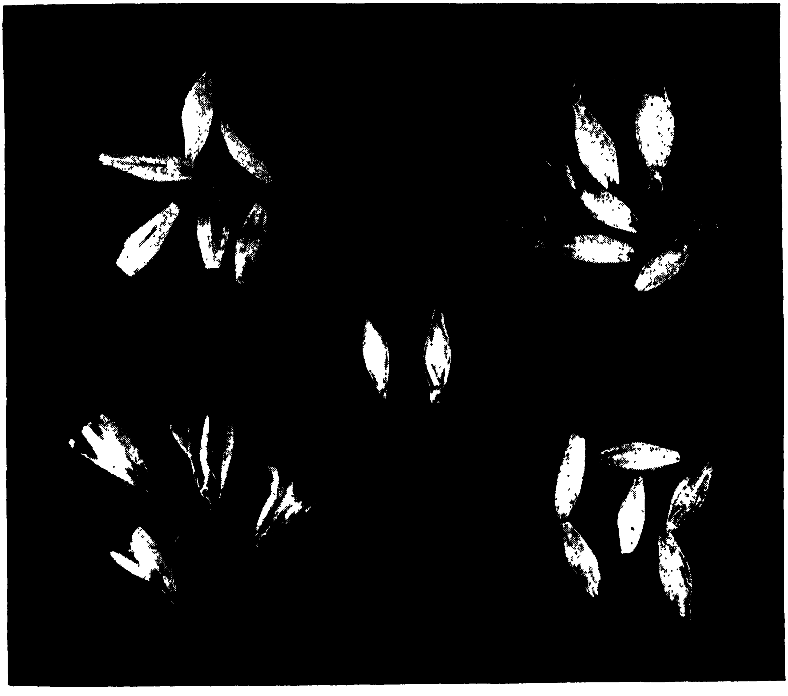

Fig. 144. Barley grains at various steps during malting process. Top—Left, original grains—Right, germinated grains. Bottom—Left, germinated grains with husks opened. Bottom—Right, finished barley malt. Center—Cross section of original grain, and of barley malt showing acrospire

kilns with more than one floor the wet grain is placed on the upper floor in layers from one to two feet deep. Heated air from below is drawn through the barley and it is raked and turned by slowly moving mechanical turners, in order to facilitate uniform drying at a temperature of from about 80 to 110°F. After drying for one to two days the floor grates on which the grain lies are opened and the grain is permitted to drop to the lower floor where the drying is completed at a temperature ranging from about 120 to 150°F. This final drying is accomplished in one or two additional days. The dried grain is then dropped through the floor grates and transferred to screens where the now shriveled, hair-like rootlets are fanned off.

Where germination is accomplished in "Pneumatic" drums, the drying or kilning is generally also done in the same drums, by blowing dry, heated air through the revolving drums.

The degree of heat used and the length of time the grain is exposed to it in the kiln determine the color of the malt. The more heat the darker the color. In the case of barley malt intended for the manufacture of malted milk a light color is desired, in order to prevent the finished product from assuming a brown color. The kilning temperature is, therefore, held as low as possible, preferably 120°F. or below.

The enzymes of the malt are very sensitive to and readily destroyed by the drying heat in the presence of moisture, such as is the case in the green wet malt. For this reason the initial temperature in the kiln should be relatively low. In the absence of moisture these enzymes are more resistant to heat. The temperature toward the end of the drying process, therefore, may be raised materially without danger of damage to the enzymic vigor of the barley malt.

The peculiar, characteristic malt flavor is understood to be derived from empyreumatic oil generated in the barley husk during the process of malting.

The dried grain, with its rootlets removed, now is called barley malt. The external appearance of the barley malt is not unlike that of the original barley grain. But inside, immediately underneath the husk we now have a small sprout called the acrospire. Samples of the kiln-dried grain are tested for diastatic value, moisture and texture.

Properly dried barley malt should contain not to exceed three per cent moisture. According to Wahl-Henius,[254] malt fresh from the kiln contains from 2.5 to 4.5 per cent moisture depending upon the final temperature of drying. It increases while in storage and after two months may contain 5.6 per cent. The original barley contains from 12.5 to 13.5 per cent moisture or slightly more. The following figures, given by J. S. Baker,[255] may serve to illustrate the difference in composition between the original barley kernel and barley malt:

Table 58.—Composition of Barley Kernel and Barley Malt

Product	Moisture	Proteins	Fat	Sugar	Starch	Fibre	Ash
Barley........	15	10	2	11	55	5	2
Malt..........	2	11	0	16	63	6	2

A portion, frequently as high as 10 per cent of the conversion products of starch, is consumed by respiration during the germinating process. High grade barley malt should have a diastase value of 130 to 140° by the Lintner scale. This means that 100 pounds of dry malt will invert 1,300 to 1,400 lbs. of soluble starch.

The finished malt as well as the original barley grain are tested for texture by use of the "Groedecker Grade Cutter." This cutter consists of a perforated plate which holds 50 kernels. The kernels assume an upright position in the perforations and are cut transversely by means of a sharp knife, revealing the condition of the center of the grain. Mellow grains show a perfectly white cross section while the cut of steely grains is bluish or glassy.

This product, the barley malt, is now ready for use in the manufacture of malted milk, the first operation consisting of the process of mashing. Barley malt contains considerably more diastase than is necessary to invert the starch contained in the barley grain itself. It has, therefore, become customary to use another grain as a source for the desired quantity of starch. For this purpose wheat flour is used in the manufacture of malted milk. Whole wheat has the additional advantage of being relatively rich in protein content, thereby adding valuable nitrogenous compounds to the malted milk.

It is the experience of the manufacturer of malted milk that a better product results by using barley malt that has been allowed to age for six to eight months, hence the practice of storing the dried barley malt for several months. Aging of the wheat flour also appears to have a similar beneficial effect.

Table 59.—Composition of Dry Matter in Barley and Barley Malt.—By LeClerc and Wahl.[256]

Ingredients	Barley Average of 84 Samples	Barley Malt Average of 30 Samples
	%	%
Fat	2.02	2.14
Fibre	5.76	5.98
Pentosan	9.64	10.56
Starch	58.87	48.39
Ash	2.98	2.69
Total phosphoric acid	1.06	1.05
Total sulphur	0.18	0.22
Lecithin	0.52	0.77
Total protein	11.86	11.52
Hulls	12.06	13.21
Bran	11.69	8.10
Embryo	2.44	5.34
Endosperm	72.69	73.31
Potash	0.70	0.39
Lime	0.08	0.08
Magnesia	0.22	0.21
Sucrose	0.00	4.61
Invert sugar	0.00	3.76 to 11.02
Weight per 1000 grains	28.14 grams	25.02 grams

Preparing the Mash.—The first step in the manufacture of malted milk proper is the preparation of the mash of wheat flour and barley malt. The purpose of the mashing process is to convert the insoluble starch and protein contained in the wheat flour and in the barley malt into soluble carbohydrates and protein-derivatives.

The proportion of malted barley and wheat flour varies with different manufacturers. It is claimed that 10 per cent barley malt contains enough diastatic strength to invert all the starch in the wheat flour, but it takes longer to convert the starch completely when the proportion of barley malt is small. Some malted milk is sold under the name "double malted." This means that the mash contained a relatively large proportion of barley malt.

The larger the proportion of barley malt used, the higher and more pronounced the malt flavor in the finished product.

Barley malt is higher in price than wheat flour. Other conditions being the same, the exclusive use of wheat flour, therefore, would lower the cost of manufacture. Wheat flour alone could be malted, but barley is desired because it is said to contribute certain desirable compounds to the finished malted milk. For this reason the medical profession demands and the Federal Standard requires the use of barley malt.

Wheat flour is used as a portion of the mash in preference to corn, because of the greater amount of protein and mineral salts contained in the wheat. Also the starch cells of the wheat flour are more easily broken up by heat than those of corn. Hence the temperature required in preparation of the wheat flour for the mashing need not be as high as would be necessary when using corn.

The starch as contained in the original wheat flour is insoluble in cold water and is not acted upon by diastatic enzymes. It is, therefore, necessary to first render it soluble. This is done by boiling up the wheat flour in hot water during which the starch cells swell and burst, forming an opalescent paste in which the starch is present in the form of so-called soluble starch. The wheat flour paste is then cooled in preparation of the mixing with the barley malt. Before mixing, the barley malt is crushed by running it through a malt mill which is of the roller type. The purpose of crushing is to open the grain and make the diastase readily accessible to the starch. The grain should not be reduced to a fine powder, as this hinders the subsequent separation of the hull from the barley malt liquid, but the crushing should be sufficiently complete to expose the contents of each individual grain. The more mellow the malt the less fine need the crushed material be.

The crushed barley malt is then mixed into a mash with the wheat flour paste. The end products resulting from the mashing process and its reactions that are most desired, are complete conversion of the starch into relatively high maltose and low dextrin content, together with reduction of the original grain proteins into simpler and more readily digestible compounds. This may be accomplished by heating the wheat flour-barley malt mixture for one-half hour at 45°C. (113°F.), then raising to 70°C.

(158°F.) at the rate of one degree centigrade per minute, which would require 25 minutes, and then holding at 70°C. for one hour. Desired variations in the end products may be obtained by slight modifications of exact temperatures and time exposures.

Rogers[257] states that the peptonizing enzyme peptase is most active at about 100 to 120°F., diastase at about 140 to 154°F., and that over 170°F. diastase action becomes very weak.

According to Browne[54] the optimum temperature of diastase is about 45°C. (113°F.). At temperatures above 60 to 65°C. (140 to 149°F.) the activity of diastase solutions is greatly reduced and above 75°C. (167°F.) its saccharifying power (power to reduce starch to maltose) is completely destroyed. However, even at 75°C. malt extract still liquefies starch, converting it into intermediate products, such as dextrins. The optimum temperature for liquefying and dextrin-forming enzymes of malt extract (malt mash) lies between 70 and 75°C.

The make-up of the starch molecule is very complex, the intermediate transition products between starch and maltose are many and their number and exact nature are still a matter of more or less uncertainty. Martin[258] suggests that the vegetable diastase is a mixture of several distinct enzymes, some of which dissolve and hydrolyze the starch to dextrins when their action stops. Others hydrolyze the dextrins to maltose. The malt contains, in addition to diastase, other enzymes, such as maltase, invertase and proteolytic enzymes.

Browne reports that at temperatures above 55°C. (131°F.) glucose begins to be formed as one of the products of starch conversion. The glucose formation increases with rising temperatures and may reach a maximum of 12 per cent of the total conversion products at a temperature of about 70°C. (158°F.) in 15 to 30 minutes. Available analyses of malted milk show no glucose present, hence it would appear that its formation in the mashing process is guarded against by proper temperature control.

The mashing of the mixture of barley malt and wheat flour in water is completed when all the starch has been converted into dextrin and maltose. This is accomplished in from 2 to 3 hours. The malt flavor is conveyed to the finished product from the husk during mashing.

Separating the Husks from the Mash.—As soon as the mashing process is complete the hulls are allowed to settle and the liquid portion of the mash is removed. This liquid extract of the mash contains in colloidal suspension, a mass of fine particles, such as proteins from the barley and wheat, which have high nutritive value and are beneficial to health. In the finished malted milk these colloidal substances obviously do not dissolve when the malted milk is mixed with water. Some manufacturers, whose aim is to produce a malted milk that is completely emulsifiable in water without showing sediment upon standing, filter the liquid extract of the mash before mixing it with the milk. Filtering removes about 20 per cent of the mash extract. Others prefer not to filter it because they desire to preserve these valuable protein ingredients in the finished product and hold that the appearance of a slight sediment in reconstituted malted milk is unimportant as compared with the greater food value, better balanced and more healthful product made from the unfiltered mash extract.

On the other hand the advocates of filtering the mash argue that the purpose of malted milk is to provide a food that is readily assimilated and that makes possible quick, if not instantaneous, invigoration of the body. They therefore hold that it should contain soluble material only in order to be of the greatest value, and that the presence of undissolved matter renders this product less valuable, i. e., not 100 per cent assimilable. They further point out that insoluble protein can be obtained at much less cost in other form than in malted milk.

It is also claimed, however, that the material thus filtered out is itself readily digested and assimilated and that its removal lowers the protein content and increases the sugar content of malted milk excessively, that this is undesirable because the product is unbalanced and tends to cause such digestive disturbances as diarrhea.

Adding Whole Milk to the Mash Extract and Drying the Mixture.—The mash extract is now mixed with fresh whole milk and the mixture is condensed and dried. The relative proportion of mash extract and whole milk is such as to cause each pound of dried malted milk to contain an amount of milk solids equivalent to 2.2 pounds of fluid whole milk. This represents an approximate proportion of 40 to 45 per cent whole milk to 55 to

60 per cent mash extract. The exact proportion varies somewhat, depending on the amount of available milk. Some manufacturers of malted milk condense the mash extract and the whole milk separately, reducing the milk to about one-third of its original volume before mixing and drying.

Small quantities of salts, such as sodium chloride and sodium and potassium bicarbonate are usually, though not always, added to the malted milk mix before drying. Some manufacturers also add protein stabilizers in the form of sodium citrate or di-sodium phosphate in an effort to more completely preserve the solubility or emulsifiability of the casein and other proteins in the product.

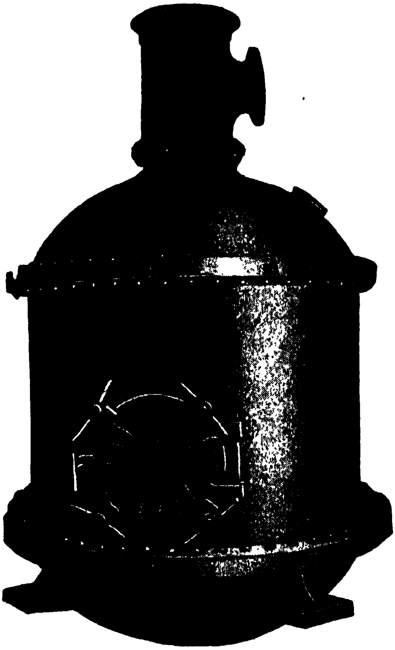

Fig. 145. Vacuum pan for malted milk

Courtesy of Arthur Harris & Co.

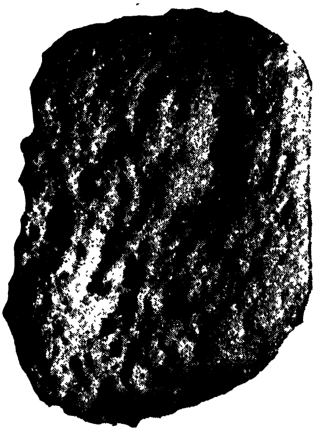

Fig. 146. Malted milk as it comes from pan, showing porous character

The condensing and drying of the malted milk mix is accomplished in several ways, either in a vacuum pan equipped with mechanical agitator or on drying drums inclosed in a vacuum chamber, or even by the spray-drying process. Great care is taken to guard against exposing the product during the drying process to high temperature which would injure the dietetic value of some of its ingredients. It is stated that in the manufacture of malted milk of the best quality the product is not subjected to temperatures above 130 to 140°F. during the drying process. In some factories the malted milk is first condensed in ordinary vacuum pans and the drying is completed in special pans equipped with powerful agitators, the operation of which requires from 60 to 80 H.P. toward the completion of the drying process. A high vacuum is maintained (about 27 inches) and in the final stages of drying the doughy mass swells up and becomes porous.

When dried in the vacuum pan with agitator the finished product comes out of the pan in the form of large chunks which have a brittle, porous, honeycomb-like make-up. The product coming from the drum driers resembles shreds of paper which readily fall apart. The spray-dried malted milk has a fine porous, fluffy grain. The malted milk of the vacuum pan-drying process and that of the drum-drying process are ground before filling into containers. The grinding and filling should be done in a perfectly dry room, as malted milk is very hygroscopic and becomes wet and gummy rapidly upon exposure to humid air.

For this purpose the grinding and packing is preferably done in a refrigerated room to prevent contact with humid air at ordinary temperature, that would make the product damp, gummy and sticky. In order to insure dry air the air, before entering the grinding room, is passed over ammonia expansion coils where it deposits its moisture and similar coils are also installed in the grinding room.

Composition of Malted Milk.—On account of the complex character of malted milk, involving both vegetable and milk protein and several sugars and dextrin, chemical analysis carried to the point of determining the percentage composition of each individual ingredient is somewhat difficult. For this reason the proteins are usually given only as total proteids and the sugars and dextrins as nitrogen-free extract. Table 60 gives the composition of several different brands of malted milk.

Keeping Quality of Malted Milk.—Malted milk is as yet the only milk powder containing whole milk that will keep indefinitely in any climate. Those who have subjected the manufacture and marketing of malted milk to careful study hold

Table 60.—Composition of Malted Milks.

Brand	Water	Fat	Fibre	Ash	Protein (N×6.25)		Nitrogen-free Extract			Calories per 100 grams
	%	%	%	%	Total Protein %	Casein %	Lactose %	Maltose %	Dextrin %	
A. D. S.*	5.93	6.75	0.13	3.08	14.06	x	....	70.05	....	3.97
Borden's (1908)*	5.42	6.14	0.23	3.17	13.38	x	....	71.66	....	3.95
Borden's (1915)*	5.18	7.15	0.05	3.45	15.38	x	....	68.79	....	4.01
Borden's (1920)**	2.55	8.98	0.45	2.93	14.38	x	....	70.71	....	x
Borden's (1923)§	2.00	8.95	x	2.77	14.11	7.40	11.81	47.60	x	x
Coor's (1923)§	2.06	8.99	x	3.84	14.91	9.25	15.71	38.40	x	x
Crary Brokerage Co. (1921)†	1.90	7.60	x	3.78	1.42	x	....	x	....	x
Horlick's (1908)*	3.63	8.36	0.00	3.70	12.94	x	....	71.37	....	4.12
Horlick's (1915)*	2.03	8.10	0.15	4.00	15.00	x	....	70.72	....	4.16
Horlick's (1920)**	3.05	8.10	0.40	3.80	15.06	x	....	69.59	....	x
Horlick's (1922)‡	3.06	8.78	x	3.86	16.35	x	49.15		18.80	4.27
Horlick's (1923)§	2.15	8.10	x	3.96	14.80	6.44	10.04	43.40	x	x
Meadows (1908)*	4.04	4.11	0.26	3.22	13.88	x	....	74.49	....	3.90
Meadows (1915)*	3.20	5.20	0.30	3.28	14.50	x	....	73.52	....	3.99
Thompson's (1920)**	4.04	7.12	0.26	3.80	10.00	x	....	74.69	....	x
Thompson's (1920)**	3.72	5.50	0.12	4.32	12.75	x	....	73.59	....	x
Thompson's (1920)**	2.74	5.40	0.09	4.65	13.50	x	....	73.62	....	x
Thompson's (1925)¶	2.86	7.64	x	4.05	12.15	x	....	73.30	....	x
Thompson's (1925)‖	2.95	8.10	x	3.85	12.15	x	....	72.95	....	x

*Street, J. P., Conn. Agr. Expt. Sta., New Haven, Conn., Bull. 213, 1919.
**Bailey, E. M., Conn. Agr. Expt. Sta., New Haven, Conn., Bull. 227, 1920.
†Bailey, E. M., Conn. Agr. Expt. Sta., New Haven, Conn., Bull. 236, 1921.
‡Horlick's Malted Milk Co. Descriptive Circular, Copyright 1922.
§Hunziker, O. F., Analyses made by Miner Laboratories, Chicago, 1923.
¶Thompson's, From Analysis shown on Label of Package, 1925.
‖Thompson's Malted Food Co., Descriptive Circular 1925.
xNot determined.

that the keeping quality of malted milk is due to the fact that the fat globules in this product are surrounded by a coating or envelope of gluten, sugars and salts which protect the fat against the deteriorating action of air.

The use of whole wheat flour, while originally a survival of "The Horlick's Food," from which malted milk was developed, may also be responsible, in part at least, for the good keeping quality of malted milk. Its large amount of gluten may assist in furnishing an effective coating for the protection of the fat globules. Experiments made with flour of other cereals gave results that did not warrant their use in the place of wheat flour.

Again, it was experimentally found that malted milks made by mere mixing of the required ingredients, also becomes stale and tallowy, and that the only product that has permanent keeping quality is that, in the manufacture of which scientific use is made of the action of enzymes and similar ferments.

As previously explained, malted milk is of high hygroscopic nature. It readily absorbs moisture and becomes wet, soft and gummy. To prevent this malted milk must be protected against humid air by keeping it in moisture-proof containers. However, even in this gummy condition the product does not appear to noticeably change in flavor.

Vitamins in Malted Milk.—Available experimental data regarding the vitamin strength of malted milk are limited. Quinn and Brabec[259] studied the vitamin potency of two "well-known" brands of malted milk with reference to vitamins A, B and G. While they found some difference between the two brands they report that on the basis of their findings both brands would be classed as good^{++} to excellent^{+++} sources of each of the three vitamins. The approximate vitamin value for both brands was as follows:

Vitamin A, 45 units per gram.
Vitamin B, 20 to 25 units per gram,
Vitamin G, 20 units per gram.

Uses of Malted Milk.—Malted milk is placed on the market in various forms. The original form and that in which the great bulk of malted milk reaches the market is the powdered malted milk packed in containers of different sizes and ranging from one pound up. In this form it serves for family use, at soda fountains, in confectioner's establishments, hospitals, etc. These containers should be kept closed to prevent rapid absorption of moisture, the product becoming moist and gummy.

Malted milk tablets are made by compressing the malted milk, making the product very compact. The tablets are somewhat more resistant to humidity than the finely powdered form of malted milk. They, therefore, lend themselves well for use under conditions where exposure to air is unavoidable. They, too, will ultimately become gummy, however, unless stored where it is dry. The tablets may be flavored with chocolate or other flavoring material.

Another malted milk product that has become very popular is chocolate-coated malted milk bars, such as Bunte's "Malteser." These are made by sawing the dry chunks as they come from the vacuum pan, into bars, dipping the bars in chocolate syrup and wrapping them in tin foil. Malted milk has also found use in bread-making.

Its high digestibility, nutritive value, dietetic virtues and health-protective properties render it most valuable as a wholesome food for infants and invalids, and its compactness and keeping qualities facilitate its transportation to and use in all parts of the globe.

CHAPTER XXXVI

MANUFACTURE OF MILK SUGAR

According to Whittier's[141] comprehensive "Review of Lactose" the sugar of milk, or lactose, was first mentioned by Fabritius Bartolettus, philosopher and physician of Mantua, Italy in 1628. The work of Albertus Haller[201] shows that lactose was made on a commercial scale as early as the first half of the eighteenth century and according to Andrea[262] it became a recognized article of commerce in the second half of the same century.

Statistics reported by Whittier indicate that up to about 1880 lactose of commerce was produced only in the Canton Luzern, Switzerland. But a few years later milk sugar factories were also established in other European countries and in the United States. A limited amount of milk sugar is also made in Australia.

The dairy by-product that supplies the source of milk sugar is whey. Milk sugar is manufactured from cheese-whey, from acid-casein whey and from rennet-casein whey. These by products are potentially capable of yielding a vast amount of milk sugar. While there are diverse uses of milk sugar for human consumption, see Chapter XXIII on "Milk Sugar," the total requirements of lactose for nutritional and prepared food

Table 61.—Annual Production of Crude Milk Sugar in the United States

Year	Production	Year	Production	Year	Production
	Pounds		Pounds		Pounds
1914	3,500,000	1921	2,890,000	1927	4,077,000
1916	1,844,000	1922	2,191,000	1928	5,323,000
1917	2,155,000	1923	2,872,000	1929	8,965,000
1918	3,291,000	1924	3,331,000	1930	12,779,000
1919	6,616,000	1925	5,655,000	1931	9,562,000
1920	5,583,000	1926	4,476,000		

purposes are limited and do not extend to over three to five million pounds annually. The relatively slight sweetness and low solubility of the refined milk sugar of commerce further limit its usefulness as a constituent of many prepared food products, and its high cost of manufacture bars its use for certain industrial purposes, such as the manufacture of certain explosives where it could be used as a substitute for glycerin. The annual production of crude sugar of milk in the United States is shown in Table 61.

PROCESS OF MANUFACTURE OF CRUDE MILK SUGAR

From Acid-Casein Whey.—The bulk of milk sugar manufactured in the United States is made from acid-casein whey (grain-curd casein whey). This whey is the by-product of casein manufacture in which the casein is precipitated by mixing dilute hydrochloric acid with skimmilk at the rate of approximately 2.6 quarts of concentrated commercial hydrochloric acid per 1,000 pounds of skimmilk. The concentrated acid is diluted on the basis of 8 quarts of water to one part of concentrated acid, before adding to the skimmilk. This yields a whey with a pH of approximately 4.2. Whey so produced has the following approximate composition:

Water	93.1 per cent
Lactose	5.0 per cent
Proteins	1.0 per cent
Ash	0.5 per cent
Fat	0.4 per cent

Heating and Neutralizing the Whey.—The whey is run into large iron tanks where it is heated with direct steam and neutralized with milk of lime that is added gradually until the whey shows a pH of 6.2. Excess of lime darkens the product, while insufficient neutralization causes troublesome foaming during the early stages of subsequent evaporation. The heating is continued to near the boiling point. This treatment coagulates much of the albumin which forms a compact layer on the surface when the boiling ceases. The clear whey is drawn from the bottom and the precipitated albumin is held over for later pressing.

Evaporating and Filtering.—The neutralized, clear whey is now drawn into the vacuum pan and condensed to a concentration of 18 to 20° Baumé. The condensing is preferably done in double-effect pan units. In case of excessive foaming in the first pan the foaming may be minimized by neutralizing to a slightly higher pH. The tendency toward excessive foaming appears to be greatest in the spring of the year, which suggests the presence of more non-coagulable albumin as the most likely cause. The thin syrup is then run through a filter, after which the protein sludge is also filtered in the same manner, and its filtrate is added to the remainder of the syrup.

Second Evaporation, Graining and Crystallizing.—The filtered whey is then further condensed in a single-effect vacuum pan. The pan is filled with the thin sugar syrup in such a manner that lactose crystals which have formed will serve as nuclei for expediting and obtaining suitable crystal growth. The last part of the condensing process (graining process) is carried on slowly to insure proper crystal formation (large crystals).

When concentrated to about 40° Baumé the contents of the pan are dropped into large crystallizing vats in which the mass is slowly agitated for one or more hours while cooling gradually to 70°F. In some plants the crystallizing period at room temperature is extended to several days for the purpose of securing satisfactory crystallization.

Centrifuging, Washing and Drying.—When, in the judgment of the operator, crystallization is complete, the sugar crystals are then separated by running the mush of crystals and liquid through a sugar centrifugal. The sugar crystals are washed in the centrifuge with cold water, adding the washings to the next batch of whey. The sugar now is quite pure, containing 85 to 90 per cent lactose. If not produced at the refinery, it must be dried to prevent spoilage. The drying is usually done on trays in a hot air tunnel. The yield of crude sugar per 100 pounds of whey does not exceed 3.75 pounds.

The mother liquor from the centrifuge may be subjected to a second crystallization. This is usually done by concentrating and allowing to crystallize in wooden boxes. The mother liquor from this second crop is high in salts and is discarded. In the place of reconcentrating and recrystallizing the mother liquor from the first crop, it may be dried for use with other hog or poultry feed.

Crude Sugar from Rennet Whey.—When using rennet whey, the whey is evaporated to a thin syrup (18°B.) before it is limed, and allowed to settle out the albuminous matter. This method is, in fact, preferred, because neutralization after condensing tends to accomplish a more complete settling of the whey. According to Nabenhauer,[263] this procedure is not suitable, however, when using acid casein whey because of the presence of phosphate ions in acid whey.

Crude Sugar from Cheese Whey.—Sweet whey only is suitable, because the reduction of the lactose content proceeds rapidly when whey is allowed to sour, making the manufacture of milk sugar unprofitable. The sweet whey is run through a centrifugal separator to remove the fat it may contain. The separated whey is then ready for the routine of milk sugar manufacture which is briefly as follows:

Removal of Albumin.—If desired, the albumin may be removed becore condensing. In this case it is precipitated by the addition of acetic acid and heating to near the boiling point. The usual practice, however, is to condense the whey first and remove the albumin and milk salts from the liquor of the heavily concentrated whey after the bulk of milk sugar has been extracted.

Condensing the Whey.—The whey is condensed in double-effect vacuum pans at a temperature of from 60 to 70°C. to a concentration of 30 to 32°Baumé, at which it contains approximately 60 per cent solids.

Crystallization of the Syrup.—When the above concentration has been attained the contents of the pan are dropped into the crystallizing vats, which usually consist of jacketed iron containers holding about 174 gallons. Cold water is circulated through the jackets and the mass is allowed to cool. The gradually thickening mass is gently agitated at intervals and after about 24 hours it has become a thick, coarse-grained, yellow mush.

Centrifuging the Mush.—The thick mush of crystallized syrup is now run through a sugar centrifuge. As soon as the separator bowl is filled with sugar crystals from which the liquor has been centrifuged out, the crystals are washed by running cold water into the revolving bowl. The centrifuge is then stopped and the wet crude sugar is removed. The yield of wet crude sugar is approximately 3.8 per cent of the original whey and it contains about 88 per cent lactose.

The mother liquor has a concentration of about 15°Baumé. It contains approximately one-third of the original lactose and most of the albumin and milk salts. These impurities are removed by boiling the mother liquor with "live" steam, allowing the coagulated mass to come to the surface and drawing off the clear liquid. The liquid is recondensed and recrystallized, and this second crop of mush is centrifuged as before. This second crop of crystals increases the total yield to about 4.3 per cent of wet crude sugar of the original weight of the whey. The second mother liquor is either discarded or utilized for fertilizer. The sludge of precipitated albumin and salts is utilized for hog and poultry feed.

REFINING THE CRUDE SUGAR

The crude sugar of milk obtained from acid casein whey, rennet casein whey and cheese whey has a yellow color and still contains considerable impurities, particularly albumin not coagulated by heat. The purpose of refining is to bleach the sugar and remove these impurities, and to thus produce the white, pure lactose of commerce.

To this end the crude sugar is redissolved in enough water at 50°C. to make a solution testing 13 to 15°Baumé, and containing approximately 24 to 27 per cent lactose. The purifying treatment used varies somewhat in detail with different manufacturers but is essentially as follows:

To the thin sugar syrup are added bone black and acetic acid. The mixture is then heated to the boiling point and a small quantity of magnesium sulphate is added. The boiling is continued until the liquid is discolorized. This treatment yields a flocculent precipitate of protein and phosphates. This precipitate is removed, filterpressed, and washed and treated with sulphuric acid to produce a fertilizer high in nitrogen and soluble phosphoric acid. The filtrate consisting of all of the sugar syrup that has thus been freed from the precipitated impurities, is evaporated in vacuo to 35°Baumé which is equivalent to approximately 65 per cent solids. It is then crystallized in the usual manner, centrifuged and washed.

According to Whittier, two more crops of crystals are obtained from the liquors by further crystallization, and the refining process is repeated until the desired quality of lactose is obtained. The purified product is dried in a rotating air dryer until the particles will not cohere when pressed between the hands. The dried sugar is then ground in an edge-runner mill and sifted to such a fineness that the particles cannot be felt between the fingers.

The yield of refined lactose averages about 2.5 per cent, or one-half of the amount contained in the original whey. The low yield of lactose is attributed to the accumulative effect of a variety of causes, the most important of which appear to be lactic acid fermentation, inversion of lactose, incomplete crystallization due to the presence of other constituents of the whey, faulty evaporation, difficulties in washing, mechanical losses of syrup due to leaky fittings and accidental spills. Nabenhauer estimates the loss resulting from refining at 10 per cent.

MODIFICATIONS IN MANUFACTURE OF CRUDE MILK SUGAR

As previously pointed out in this chapter, the vast supply of available raw material—whey—provides possibilities for the annual production of milk sugar far in excess of the present market demand. The dominant limitations of the demand for milk sugar lie in its high cost of manufacture.

Efforts to reduce the cost and increase returns have led to the suggestion of several other methods of manufacture. The more important of these are: Evaporation of the whey to dryness and extraction of the lactose with water, as proposed by Hatmaker;[264] and evaporation of the whey on some suitable absorbent such as Kieselgur (infusorial earth) with subsequent leaching of the lactose, as suggested by Just.[265]

More recent experimental research by Bell, Peter and Johnson,[266] and by Webb, Rogers, Johnson and Ramsdell[267] has revealed possibilities of simplifying the present process, increasing the yield, improving the purity of the lactose and augmenting the usefulness and market value of the by-product of sugar manufacture. These modifications are briefly outlined below:

PROCESS OF RECOVERY OF CRUDE SUGAR OF MILK WITHOUT BOILING AND FILTER-PRESSING

This modification was developed by Bell, Peter and Johnson. It differs from the usual commercial procedure in that it eliminates the boiling and filterpressing, reduces the evaporation to one condensing operation, increases the yield and yields the by-product in soluble form.

Source of Whey.—Sweet whey is required. Swiss-cheese whey and rennet-casein whey are preferred, because of absence of fermentation and low salt content, but the process is applicable also with cheddar-cheese whey and acid-casein whey. For most satisfactory results the whey should have a titratable acidity of 0.2 per cent or less. The whey is run through a whey separator to remove the fat.

Neutralization.—The fat-free whey is neutralized with a 5 per cent solution of NaOH to pH 7.3, or a titratable acidity of 0.04 per cent. It was found essential to attain this reaction in order to prevent the formation of slime in the sugar centrifuge. Because of the immediate and severe action of NaOH, the neutralizer must be dispersed quickly throughout the whey to prevent localized precipitation of proteins and salts.

Condensing the Whey.—If preheated at all, the temperature of the neutralized whey should not be raised above 60°C. (140°F.). Equally satisfactory results are obtained without preheating. Condensing to a concentration of 32°Baumé at 131°F., or to a total solids content of 64 per cent is recommended. Higher concentrations are preferable but above 64 per cent solids the whey becomes too sluggish for satisfactory handling at 0°C. or below. Concentrations below 62 per cent solids diminish the yield excessively.

For best results after condensing, crystallization should take place as much as possible in the vacuum pan. To this end the graining process used in commercial practice is most effective. The steam coil type of vertical pan is more suitable for satisfactory graining than the rapid circulation type of pan with milk tubes and steam chest.

Crystallization.—Satisfactory crystallization was obtained by cooling the condensed whey in cans first to 25°C. (77°F.) and stirring and then setting the cans in the cooler at 4°C (39.2°F.) for 42 hours; or without stirring, by leaving the cans in the cooler at 0°C. (32°F.) for 18 hours. For commercial operation suitable crystallizing tanks with adequate stirring and cooling facilities will undoubtedly produce equally satisfactory results with less labor. Lower temperatures failed to increase the yield but produced a larger and dryer crystal most suitable for centrifuging. Crystallization at higher temperatures and for shorter periods yielded less desirable material for centrifuging and decreased the yield.

Centrifuging, Washing and Drying.—The cooled, crystallized whey is centrifuged, and the crystals washed and dried in the usual manner as described earlier under "Commercial Manufacture." When made from whey condensed to 62 per cent solids or more, the yield of crude sugar averaged 5.25 pounds per 100 pounds of whey and its lactose content ranged from 85.54 to 91.1 per cent.

Utilization of Liquor.—The liquor from the sugar centrifuge was not suitable for recondensing to obtain a second crop of crystals. It is therefore not used for added sugar extraction, but because of its richness in soluble food nutrients, it promises more profitable utilization through other channels. Its composition was as follows:

Ash	3.52 to 5.10 per cent
Protein	10.86 to 13.56 per cent
Lactose	19.65 to 21.12 per cent
Total solids	35.50 to 40.54 per cent

If stored, the liquor should be held at low temperature to prevent fermentation and spoilage. It appears to be subject to age thickening. At room temperature it jells in a few days. Bell and co-workers dried the liquor by the spray process and by the vacuum drum process and secured a soluble powder of a light yellow color. This powder, consisting of the nutritionally highly valuable lactalbumin, milk sugar and soluble milk salts recommends itself as a desirable component of modified milk, and should materially increase the market value and returns from the by-products of the manufacture of crude sugar of milk.

PROCESS OF THE MANUFACTURE OF HIGH GRADE TECHNICAL LACTOSE BY THE USE OF TRYPSIN

This process was developed by Webb, Rogers, Johnson and Ramsdell.[267] Its purpose is to so modify the present method as to obtain a good grade of crude or technical lactose substantially free from protein and other impurities, without the necessity of a second crystallization (refining) with its inevitable expense and loss of yield.

It is chiefly the protein impurities which render a high grade crude sugar of milk unfit for various uses. These protein impurities consist principally of albumin not coagulable by heat. This non-coagulable albumin is gradually precipitated as the result of an increasingly high salt content of the whey which is built up as the water is removed. These progressively accumulating protein precipitations coat the heating surface in the vacuum pans and contaminate the crystallizing lactose, necessitating recrystallization or refining to accomplish complete removal. Webb and co-workers succeeded in preventing much of this troublesome precipitation by the use of the enzyme trypsin, which splits the protein into smaller and more soluble molecules, thus facilitating the protein elimination from the sugar. These investigators recommend the following procedure for the manufacture of a high grade, low protein lactose with one crystallization, from acid-casein whey.

"Lime the whey to obtain a reaction of pH 6.2 to 6.3; boil and decant or filter off the clear whey. Adjust the temperature to 56-58°C., add trypsin at the rate of 1 part in 10,000 and hold the temperature between the above limits for one hour, or until digestion has been shown to be complete by the trichloro-acetic acid test. Evaporate the whey to 18 to 20°Baumé and filter, using approximately 1/10 per cent of decolorizing carbon by weight of the lactose present in the raw whey. The amount of carbon to be used will, of course, depend upon its activity in removing the milk pigment. Condense the whey to 40°Baumé, graining the product in the pan. Remove from the pan and allow to crystallize. The sugar may now be centrifuged and washed. The resulting product should be very low in protein, give a clear solution in water, and very little or no foam on boiling."

THE MANUFACTURE OF QUICKLY SOLUBLE LACTOSE (BETA-ANHYDRIDE)

Solubility and Sweetness of Alpha and Beta Lactose.—Milk sugar exists in two forms, the alpha and beta lactose, as explained in Chapter XXIII on "Composition and Properties of Condensed Milk." The alpha lactose is of two kinds, the hydrate and the anhydride. The milk sugar of commerce consists of the alpha hydrate form, which has but slight sweetness and is of relatively low solubility. Both the lack of sweetness and the low solubility of milk sugar are attributes that greatly limit its usefulness for various medicinal and dietary purposes, for which it would otherwise be highly desirable.

Beta lactose, on the other hand, is readily soluble and, probably because of its greater solubility, has the desired sweetness to taste. It follows, therefore, that a modification in the process of manufacture that would yield beta lactose instead of alpha lactose would greatly assist in increasing the usefulness and extending the available markets for lactose.

The Alpha-Beta Equilibrium.—It was explained in Chapter XXIII that when milk sugar of commerce (alpha hydrate) is dissolved in water a certain portion of it will readily change to beta lactose, the proportion and rapidity of such conversion depending upon the temperature of the solution. Likewise, beta lactose will change to alpha lactose. When the conversion has been completed the lactose solution is in equilibrium, that is, it contains such proportion of alpha lactose and beta lactose as is normal for that particular temperature. Thus, according to Rahn,[61] the beta-alpha ratio for different temperatures is as follows: at 25°C., 1.58:1; at 50°C., 1.51:1; at 70°C., 1.45:1; at 90°C., 1.40:1; at 100°C., 1.33:1.

Under normal conditions alpha lactose, because of its lower solubility, will crystallize out at lower temperatures, and beta lactose, because of its higher solubility, will crystallize out at higher temperatures. The temperature below which the alpha form and above which the beta form will crystallize out is spoken of as the transition point. This temperature is approximately 93°C. (199.4°F.). In other words, alpha hydrate is the stable solid form below 93°C., and beta anhydride is the stable solid form above 93°C. At the temperature of the transition point, the proportion of alpha to beta lactose is approximately 1 to 1.38. At higher temperatures the solution becomes supersaturated with respect to beta lactose.

Conversion of Alpha to Beta Lactose.—Sharp,[268] however, discovered that in the presence of a large quantity of beta crystals and in the absence of any considerable proportion of alpha crystals, beta crystals may be formed by heating a saturated solution of lactose at much lower temperature than 93°C. (as low as 83 and even 78°C.).

Sharp further reports that beta crystals may be produced in commercial quantities without substantial admixture of alpha crystals, by crystallization from lactose solutions containing undissolved alpha crystals, by maintaining the temperature of the solution above the transition point, by providing conditions that prevent evaporation of the solvent, and by subsequent removal of the mother liquor from the crystals under conditions that will not permit the formation of appreciable quantities of alpha crystals. Sharp found that in solutions supersaturated with beta lactose at temperatures above the transition point and containing an excess of alpha lactose, such excess will go into solution, and beta lactose will go out of solution in the form of beta crystals. This crystallizing-out of beta lactose disturbs the equilibrium of the solution, but it is immediately restored by the conversion of more of the dissolved alpha lactose into beta lactose. The latter continues to crystallize out causing more alpha to go in solution until all the excess alpha lactose has dissolved.

When this point is reached there is then present in the magma beta crystals and the mother liquor composed of a solution of alpha and beta lactose in equilibrium. If the crystals present are now separated from the liquor under conditions unfavorable to the formation of alpha lactose crystals, the crop of crystals will consist of beta crystals only.

Trials in Commercial Manufacture of Beta Anhydride Lactose.—Methods of preparing beta anhydrous lactose had been published by Erdmann[269] and by Hudson and Brown[270] prior to the work of Sharp, but it is the application of these findings by Sharp[268] and by Bell[271] that resulted in methods suitable for commercial manufacture.

Bell used 10 and 20 per cent solutions of commercial milk sugar, and after forewarming at 60 to 100°C. dried them by the Gray-Jensen spray process. The resulting powder was highly soluble due to the porosity of the sugar grain. The dried sugar, however, proved to be a mixture of alpha and beta lactose in the ratio in which they occur in an equilibriated solution. This was attributed to the fact that the water was evaporated so quickly that the alpha form did not have time to change to the beta form as the solute was precipitated from solution. Bell further reports that "there was no indication in any of the trials with the spray drying units that the ratio of solid beta to solid alpha lactose could be increased in favor of the beta form."

On the other hand, trials by Bell with drum dryers showed that nearly pure beta lactose can be made by desiccating equilibriated milk sugar solutions on either the vacuum drum or the atmospheric drum dryers.

A Practical Method of Procedure.—The following appears to be a satisfactory, practical method of manufacturing beta lactose commercially.

Use a lactose as nearly pure as possible, dissolving it at the rate of 60 pounds of sugar to 40 pounds of water. Heat the solution to near 92°C. for one-half hour. Then apply the solution to an atmospheric drum dryer and conduct the drying in such a manner as to yield a powder of crystalline structure, rather than of amorphous form. This is done by the proper adjustment and relationship of the speed of feeding the saturated sugar solution and the steam pressure maintained on the drums. Special precautions must also be taken when making this powder to hold its moisture content at or below 1 per cent and to pack the finished product in moisture-proof containers.

PART VII

Tests, Analyses, Standards, Tariff

CHAPTER XXXVII

FACTORY TESTS AND CHEMICAL AND BACTERIOLOGICAL ANALYSES

FACTORY TESTS OF FLUID MILK

The purpose of these tests is to determine the suitableness of the fluid milk received at the factory for the manufacture of condensed, evaporated and dried milks. The relative merits of the several platform tests for condensery purposes are discussed in Chapters III, XII and XV. The technique employed in the use of these tests is briefly described in the following paragraphs.

ACID TESTS (TITRATABLE ACIDITY)

Apparatus—50 cc. burette, graduated to 0.1 cc., with stand and connections with supply of sodium hydroxide solution in bottle and pinch cock.

Titrating cup with stirring rod.

17.6 cc. pipette.

Reagents.—Tenth normal solution of sodium hydroxide in bottle provided with soda-lime tube to protect the alkali solution against CO_2.

Phenolphthalein indicator, made up by dissolving one-half gram of dry phenolphthalein powder in 50 cc. of alcohol and, when dissolved, diluting the solution to 100 cc. with distilled water.

Complete acid outfits including glassware and reagents may be obtained from dairy supply houses.

Determination.—Measure 17.6 cc. of the milk into titrating cup and add 4 to 5 drops of the indicator. Run alkali solution slowly from burette while constantly stirring the sample, until the milk in the cup turns a faint pink throughout. If end point is in doubt, add another drop of indicator. This should turn pink when it strikes the milk, if the end point has been reached. The number of cc. of alkali used as shown on the burette, divided by 20, gives the per cent acid.

RAPID ACID TEST FOR DAILY USE IN FACTORY

Dilute 200 cc. of the tenth normal alkali solution with 790 cc. of distilled water and add 10 cc. of indicator. This makes a one-fiftieth normal alkaline solution, each cc. of which neutralizes .01 per cent lactic acid. 18 cc. of this solution therefore neutralizes 0.18 per cent acid in the milk, when a 17.6 cc. (18 gram) pipette is used for measuring the milk. The one-fiftieth normal alkali solution should be made fresh each day.

With the Babcock pipette, measure 17.6 cc. into a white cup. With a small dipper, holding exactly 18 cc., pour 18 cc. of the above $\frac{N}{50}$ solution into the cup; stir or shake. If the mixture remains faintly pink, it contains less than .18 per cent acid; if it turns white, it contains more than .18 per cent acid. An acidity in excess of .18 per cent suggests the presence of considerable developed acidity. It is considered good condensery practice to adopt a maximum acid limit of .18 per cent titratable acidity.

THE ALCOHOL TEST

Mix equal parts, by volume, of 75 per cent alcohol and milk and examine the mixture for presence or absence of coagulation. For commercial work use a block of wood similar to that used for Babcock test bottles, but with smaller diameter holes to hold small size test tubes such as are used in the chemical laboratory. Use not less than 2 cc. each, of milk and alcohol. Measure the milk and alcohol into the test tube with two pipettes or two small size dippers of equal capacity. When using dippers keep the alcohol in a wide-mouth bottle to facilitate removal of reagent. Before examining, invert each test tube once or twice, while holding finger over top, so as to insure complete mixture.

If no coagulation takes place the mixture recedes from the glass leaving the sides clear. In case of a fine precipitate the walls of the glass tubes are cloudy. Intense coagulation shows small lumps. This test is very simple, it is easily and quickly made and the reaction is sharp. If coagulation occurs in the mixture the milk may reasonably be expected unsafe from the standpoint that it may not stand the necessary heat in the sterilizer without becoming objectionably curdy.

THE PHOSPHATE TEST

This test was developed by Ramsdell, Johnson and Evans[32] who determined the relationship of heat coagulation and the coagulation of milk in the presence of mono-basic potassium phosphate (KH_2PO_4). It consists of adding to the milk sample a definite amount of a dilute solution of KH_2PO_4.

Reagent.—Dissolve 68.1 grams of mono-basic potassium phosphate in water and dilute the solution to 1 liter. This represents the phosphate solution to use for the test.

Determination.—Measure 10 cc. of the milk sample into a test tube, using a 10 cc. dipper. Add 1 cc. of the phosphate solution, preferably from 25 cc. burette. Mix the contents of the tube thoroughly and then immerse in boiling hot water for five minutes. The water bath should reach above the contents of the tube to insure the required heating. After five minutes remove the tube from the bath, cool, and examine the contents for presence of curd. Visible coagulation indicates low heat stability of the evaporated milk in the sterilizer.

According to Ramsdell et al, the elimination from a batch of milk of those lots which curdle in this test, does not always improve the heat stability of the batch. They suggest that when grading out milk, on the basis of the 1 cc. of phosphate solution per 10 cc. of milk, fails to produce increased stability in the remaining batch, the use of a smaller proportion of phosphate solution may prove helpful.

This test is not intended for use as a quality test of sanitary milk. Its chief aim is to aid in picking out those milks that impair the heat stability of the total composite during the seasons when sterilizing difficulties are encountered.

THE BROM-THYMOL BLUE TEST

This test determines the hydrogen ion concentration colorimetrically. Its pH range is pH 6.0 to 7.6. Its color at different hydrogen ion concentrations may be described as follows:

At pH 6.00	yellow
At pH 6.58	light olive green
At pH 6.65	dark olive green
At pH 6.80	light grass green
At pH 7.00	bluish green
At pH 7.60	blue

According to Benton and Albery,[85] within the pH range of 6.58 and 6.65 the influence of the hydrogen ion concentration on heat coagulation is slight, being overshadowed by the salt balance. Above and below this pH range, on the other hand, changes in pH produce a marked effect on heat stability. It would appear, therefore, that the colors of the brom-thymol blue test that coincide with a pH below 6.58 or above 6.65 suggest probable heat coagulation difficulties. The use of this test with milk has its drawbacks because of the turbidity of milk which detracts from the sharpness of the color reaction.

The brom-thymol blue test is recommended particularly for the determination of the suitability of the water used for dissolving corn sugar in the manufacture of sweetened condensed milk in which dextrose is used. Such water should be free from alkali and should show a pH below 7.0, preferably pH 6.8.

Apparatus.—Test tubes and test tube rack.

One of the following color standards for comparison:

1. Set of test tube color standards covering the b.t.b. range (pH 6.0 to 7.6), or
2. A single tube of solution at pH 6.8 colored with b.t.b., or
3. A color chart covering the b.t.b. range (pH 6.0 to 7.6).

The color standards recommended in No. 1 are preferred because of maximum accuracy. No. 2 is equally accurate for comparison at pH 6.8, but fails to provide direct comparisons at any other pH. No. 3 is the least dependable, as printed color charts are seldom as accurate as they should be and usually change with age.

Reagent.—Solution containing 0.04 per cent brom-thymol blue dye in water.

Determination.—Place 10 cc. of the fluid to be tested in a test tube and add 0.5 cc. of the brom-thymol blue solution. Compare with color standard.

DIRECT MICROSCOPIC EXAMINATION

The method recommended for microscopic examination of milk is the Breed Method[276, 277]. This is a simple and accurate method for direct examination under the microscope. It consists of transferring, with a capillary pipette, .01 cc. of the milk to a clean glass slide and spreading it uniformly over an area one square centimeter by means of a stiff needle. The film of milk is then dried by putting the slide in a place sufficiently warm to accomplish the drying in five minutes. The slide with the dried film is then dipped into a fat solvent, such as xylol, to remove the fat, then drained and dried again. It is next immersed in 90 per cent grain alcohol and then placed in a solution of methylene blue, leaving it in until overstained. The slide is then rinsed in water, decolorized in alcohol and, after drying, it is ready for examination under the microscope.

In place of the above technique involving three operations, the one-solution procedure of Newman[288] may be used. The

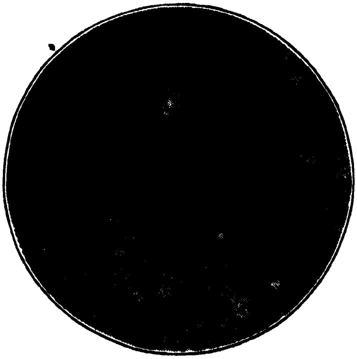

Fig. 147. Microscopic appearance of milk from a cow suffering from mastitis

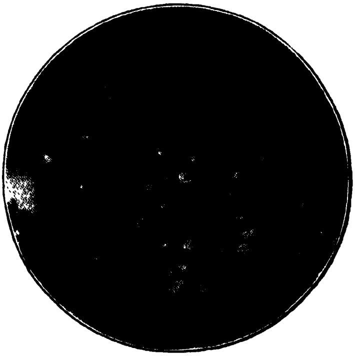

Fig. 148. Microscopic appearance of milk that has been held in poorly cleansed milk cans

Courtesy of Bausch and Lomb Optical Co.

fat solvent, fixative and methylene blue stain are combined in one solution, facilitating the handling of a large number of samples. This solution, known as Newman-Lampert Formula No. 2, may be obtained from dairy and chemical supply companies.

The microscope is standardized by means of the stage micrometer, to a definite area of field, from which the number of fields in 1 square cm. may be calculated. From the number of bacteria per field (usually representing the average of a number of fields) the total number of bacteria per cc. of milk is obtained. In order to secure dependable results the numerous details of technique must be correctly performed and the test requires considerable skill in preparing the slide, and training in the standardization and proper manipulation of the microscope. Detailed directions for the Breed method of direct microscopic examination of milk are given in Standard Methods of Milk Analysis[278] and a complete atlas of the microscopic appearance of market milk and cream has been prepared by Breed.[279]

FERMENTATION TESTS

The tests are of value in the rapid determination of the kind of bacteria with which the milk from individual patrons is contaminated. Freshly steamed or boiled glass tubes are filled one-half full of milk from each patron. These tubes are set in constant water bath at 98 to 100°F. and the changes which milk undergoes are noted after six, twelve and twenty-four hours.

A solid curd with a clear whey indicates that lactic acid bacteria are the chief organisms and that the milk has been produced under cleanly conditions. These organisms are killed when the milk is heated in the hot wells. Such milk, therefore, may be considered safe as far as its influence on heat coagulation is concerned.

A curd with gas holes, or which is torn to pieces in the tubes, shows the presence of gas-producing germs. These may come largely from manure, unclean milk utensils, or from grain feeds or bedding. Among this type of contamination may be mentioned such organisms as B. coli communis, the natural inhabitant of the colon, butyric acid organisms and the group of

B. aerogenes, all of which are capable of causing serious condensed milk defects, even to the extent of producing bloats. Their presence in milk is usually evidence of insanitary conditions in the production and handling of the milk on the farm.

If the curd dissolves, or no curd is formed and the milk changes into a transparent liquid, it usually is contaminated by germs from the dust of hay and bedding, or polluted water. To this class of organisms belong Bacillus subtilis, Bacillus fluorescens liquifaciens, Plectridium foetidum, Bacillus putrificus, etc. Some of these are violent gas producers and most of them are sporebearers. They are the cause of the most disastrous milk defects.

Milk that remains unchanged for twenty-four hours when subjected to the fermentation test, suggests that it contains some preservative. It is possible, however, for milk produced under ideally sanitary conditions to remain normal and unchanged even at these high temperatures for several days. When milk comes to the factory in bulk as is the case in the condensery, samples showing abnormal keeping quality should be regarded with suspicion, and their source investigated.

THE METHYLENE BLUE REDUCTION TEST

This test, also called the "Reductase Test," is based upon the disappearance of the blue color imparted to milk by the addition of a small amount of methylene blue, the time required for the decolorization being correlated in a general way with the number of bacteria present.

Barthel,[289] whose theory appears to be supported by the majority of investigators of the subject, holds that the disappearance of the methylene blue in milk takes place in two stages, as follows:

1. The removal of the dissolved oxygen by the growing bacteria. This stage, briefly, is a test of the oxygen-consuming power of the bacteria present. This stage is usually a long one, and while it lasts there is no decolorization of the milk.

2. The reduction of the blue dye by the constituents of the milk. The time required for this stage is usually short. It is during this stage that the blue color bleaches out. The reduction of the dye involves no change of oxygen, since there is

no oxygen in the methylene blue molecule. The reduction appears to be due to absorption of hydrogen by the dye, the hydrogen changing the methylene blue to methylene white. Barthel believes the citrate in milk to be the hydrogen source.

Apparatus and Reagents.—

Glass test tubes 6″ x ¾″, with cork or rubber stoppers
10 cc. pipettes or 10 cc. dippers
1 cc. pipettes
Test tube rack
250 cc. flask or 8 oz. prescription bottle
Water bath, preferably with electric thermostatic control
Thermometer
Gas or alcohol burner
Methylene blue tablets (National Analine Co.),

Complete and compact sets of apparatus for the reduction test are furnished by dairy and chemical supply houses.

Sampling.—Samples may be taken into the test tubes direct from the farmers' cans or from the factory weigh can by means of the 10 cc. dipper.[278] The dipper should be rinsed first in cold water and then in very hot water between samples. If tests cannot be made immediately, take samples with sterile sampling tubes into sterile, wide-mouth sample bottles with glass stoppers and place samples in ice water until ready to make the test. Mix the milk in the cans thoroughly before sampling.

Preparation of Methylene Blue Solution.—Dissolve tablets in proportion of 1 tablet per 200 cc. of water. Use boiled distilled water. Solution is facilitated by placing the tablet in a portion (50 cc.) of the water heated to boiling; then add the remainder of the cooled water. This will give the correct strength of methylene blue solution, which is 1:20,000, making the desired concentration of methylene blue dye in milk of 1:200,000.

Making the Test.—"Line up" sample bottles numerically and number the freshly steamed or boiled test tubes in the rack to correspond with patrons' numbers on sample bottles.

Invert sample bottles for thorough mixing just before use, and transfer, with freshly cleaned pipette, 10 cc. of the milk to the respective test tubes. For each succeeding transfer of milk thoroughly rinse the pipette, first in cold water, then in very hot water.

When tray of test tubes has been filled, add 1 cc. of methylene blue solution to each tube, mix well by inverting the tubes.

Set tray in water bath at 98.6°F. Maintain uniform temperature by means of burner. For operation of a large number of tests daily, thermostatic temperature control is advisable. Where an incubator is available, the rack may be placed in it without water bath after the temperature of the test tubes has been raised to 98.6°F. in the bath.

Interpretation of Results.—Examine the tubes at definite intervals. The quality of the milk is judged on the basis of the rapidity with which the blue color disappears. In some cases the milk does not decolorize uniformly throughout the tube. When this occurs, mix gently so as not to disturb the cream layer and take as the final reading the time when the milk after mixing shows no blue color. The following classes of milk are recognized in "Standard Methods of Milk Analysis:"[278]

Class 1. Good milk, not decolorized in 5½ hours.

Class 2. Milk of fair average quality, decolorized in less than 5½ hours but not less than 2 hours.

Class 3. Unsatisfactory milk, decolorized in less than 2 hours but not less than 20 minutes.

Class 4. Very unsatisfactory milk, decolorized in 20 minutes or less.

CHEMICAL ANALYSIS

For complete chemical analyses of milk and condensed and dried milk products the reader is referred to "Official and Tentative Methods of Chemical Analysis," 3rd Ed., published by the Am. Asso. Official Agr. Chemists, Washington, D. C. (1933.)[280]

For determinations of fat, milk solids and total solids by the Mojonnier Method, detailed directions accompany the Mojonnier tester and are also contained in "Technical Control of Dairy Products" by Mojonnier and Troy.[42]

For standard methods of chemical and physical tests of milk powder see also "Grades and Methods of Analyses of Dry Skimmilk" by Thompson, Slemmons and Fleming, Standards Committee of the American Dry Milk Institute.[281]

BACTERIOLOGICAL ANALYSIS

Glassware.—Sterile glassware is indispensable for all bacteriological work. It is recommended that an exposure to a temperature not less than 170°C. for not less than one hour in the hot air sterilizer be used.

Media for Total Plate Count.—When desired to secure uniform results comparable with those of other laboratories, use the standard beef extract agar prescribed by the American Public Health Association.[278] This medium, together with others which have been suggested for plating milk and milk products, is available in dehydrated form (Bacto brand) from the Digestive Ferments Co., Detroit, Mich. For investigational work demanding maximum bacterial counts, beef infusion agar is recommended.

Beef Infusion Agar.—In the preparation of this medium the following ingredients are used:[283]

1 lb. lean ground beef
5 grams peptone (Bacto or other brands giving similar results)
15 grams agar (e.g. Bacto granular)
1 liter distilled water.

Reaction of finished medium—pH 6.6 to 7.0.

Preparation.—Place the ground beef in about 500 cc. of distilled water and stir until completely mixed. Allow to stand overnight in a cold room. Then strain by squeezing through cheese cloth and make up volume to 500 cc. with distilled water. Add the peptone, mix and warm to 50°C.

Dissolve the agar in 500 cc. distilled water by boiling and add water to make up loss in weight due to evaporation. Cool to 50°C., add to beef infusion, and mix thoroughly. Adjust reaction as directed under "Acid Reaction" and heat in flasks in autoclave under 15 lbs. pressure for about 45 minutes to precipitate the albumin and secure a clear medium. Filter through absorbent cotton, fill into flasks or tubes and sterilize at 15 lbs. pressure for 20 to 30 minutes depending upon size of containers and number in autoclave.

Acid Reaction.—The pH of the finished medium may vary between the limits of 6.6 and 7.0. Any adjustment of the reaction must be made prior to the first heating in the autoclave. A sample of the agar immediately after mixing may be boiled to precipitate the albumin and clarify, then filtered into a test tube from which a sample may be taken for hydrogen-ion determination either by the electrometric or colorimetric method. Using the indicator brom thymol blue, 5 cc. of the clear agar is added to 5 cc. of distilled water at 30 to 40°C., then add 0.5 cc. of the indicator. The resulting color should be a yellowish green. A set of color standards for the pH range 6.0 to 7.6 may be purchased from chemical supply houses and used for comparison. If the right color is not secured, adjust reaction as directed in "Standard Methods of Milk Analysis," 6th edition.[278]

THE PLATE METHOD FOR TOTAL BACTERIAL COUNT MILK

Sampling.—Use sample containers and sampling methods recommended in "Standard Methods of Milk Analysis."[278] A convenient sample and dilution bottle is a 4 ounce round prescription bottle provided with a screw cap. Place samples in ice water until ready to use.

Dilution of Milk Sample.—The number of bacteria contained in the milk at the receiving platform varies within wide limits, ranging from a few thousand to over 1,000,000 bacteria per cc. For satisfactory counts the plates should contain between 30 and 300 colonies. It is necessary, therefore, to plate several dilutions if the character of the milk is not accurately known. Duplicate plates should be poured from each dilution.

Prepare 99 cc. water blanks by sterilizing distilled water in the dilution bottles under steam pressure of 15 lbs. for 20 minutes. Usually 1 cc. is lost in sterilization. Transfer with sterile pipette 1 cc. of the sample to one of these water blanks. Shake vigorously 25 times, each shake being an up-and-down movement of about one foot (Standard Methods). This represents a 1:100 dilution. Place 1 cc. of this dilution in each of two sterile Petri dishes.

Add 0.1 cc. of the same dilution to each of two more dishes for the 1:1000 dilution and add 1 cc. to a second water blank to make a 1:10,000 dilution. Shake as before and transfer 1 cc. to each of two more dishes. Use a separate sterile pipette for each dilution bottle. If still higher dilutions are desired the above procedure may be carried further. Usually it is sufficient to plate three dilutions even when the sanitary condition of the milk is unknown. What dilutions to plate is determined only by experience with each milk supply.

Plating.—After transferring the desired dilutions to the plates pour about 10 cc. of the melted agar, cooled to 40°—45°C., into each plate and mix agar and dilution with a rotary motion. Allow to solidify on a level surface, invert plates and place them in incubator at 37°C. Make colony counts after 48 hours, averaging the two plates of the dilution selected for counting and multiplying by the dilution to get the "total plate count."

SWEETENED CONDENSED MILK

Sampling.—To obtain a representative sample of sweetened condensed bulk milk use a wide-bore, sterile, glass sampling tube and transfer a quantity from below the surface in the container to a sterile, wide-mouth, glass-stoppered bottle.

In case of sealed tins, clean the top of the can thoroughly with soap and water and sterilize in the gas flame. Open with a can opener sterilized in the flame and mix the contents thoroughly with a sterile tube.

Dilution.—Weigh 10 grams of the product into a dilution bottle containing 90 cc. sterile water. This, then, represents a 1:10 dilution. Shake thoroughly to secure a homogeneous solution and prepare further dilutions if needed as directed under "Milk." Under ordinary conditions the bacterial count of normal sweetened condensed milk is such that dilutions of 1:10 and 1:100 are sufficient; the latter may be secured by placing 0.1 cc. of the 1:10 dilution in each plate.

Medium.—Beef infusion agar is recommended.

Plating.—Plate as directed for milk and incubate at 37°C. for 2 days. Express results as "colonies per gram."

EVAPORATED MILK
UNSWEETENED CONDENSED MILK

Sampling.—Plain condensed bulk milk may be sampled by the same method as the sweetened bulk product. In case of evaporated milk sterilized in sealed tins, first mix contents by shaking. Sterilize top of can as described under "Sweetened Condensed Milk" and make opening with sterile can opener large enough to admit a 1 cc. pipette. If the product in the can is abnormal and not in a fluid condition, cut the top open and mix contents with a sterile spoon or spatula.

Dilution.—For the normal fluid product, transfer 1 cc. to a test tube containing 9 cc. sterile water, making a 1:10 dilution. For the abnormal, coagulated product, weigh 10 grams into a dilution bottle containing 90 cc. water to secure the 1:10 dilution. Further dilution may be made from this as the bacterial content of the abnormal product is apt to be high.

Normal evaporated milk should also be plated direct by transferring 1 cc. of the product into each plate. This is essentially a test for sterility and may be supplemented by inoculation of 1 cc. direct into a tube of litmus milk for incubation and detection of bacterial growth.

Medium.—Beef infusion agar is recommended.

Plating.—Plate as directed for milk, and incubate at 37°C. for 2 days. Express results as colonies per cc. or grams, as the case may be.

Test for Sterility.—For a routine check on the sterility of the product it is recommended that sample cans be incubated at 37°C. for one week, when they should be opened for examination and plating. If the milk has developed an abnormal condition, organisms may be present in large numbers and the product should be plated to demonstrate their presence. Several dilutions should be plated to obtain an accurate plate count. Milk which is in normal condition after the one week's incubation and which does not yield any colonies on any of the plates may be assumed to be, for all practical purposes, sterile.

MILK POWDER

For the bacteriological examination of milk powder the reader is referred to the Report of the Sub-Committee of the American Dairy Science Association.[282]

For the total plate count, a 1:10 dilution is made by weighing 10 grams of powder into a dilution bottle containing 90 cc. sterile distilled water and continuing the plate method as described for milk. While the standard beef extract agar may be used, beef infusion agar will be found to give slightly higher counts and larger colonies. Other media for special purposes are included in the Committee Report.

QUALITATIVE METHODS OF ANALYSIS

The method and media employed for qualitative bacteriological examination must of necessity vary with the specific aim of such analysis. Thus, it may be desired to determine the number of organisms of various types present, or to investigate the cause of a specific defect, or to establish the exact cultural characteristics of the bacteria present for systematic classification of species.

Study of Types Present.—The purpose here is to get a general idea of the comparative numbers of the various types, such as acidifiers, proteolytic types, gas producers, yeasts, molds, etc. Thus the predominating type of organism present may be ascertained, which is usually helpful in identifying the one responsible for a certain defect. Some of these types are capable of disastrous fermentations. For sources and effect of these species see Chapters XXV and XXVI on "Condensed Milk Defects." In milk powder their presence suggests high rate of multiplication before drying and incomplete destruction during the drying process, or profuse contamination in handling between dryer and sealed package.

Acidifiers.—Use beef infusion agar (or standard beef extract agar) to which has been added 2% lactose before sterilizing. Before pouring the agar add to each plate 1 cc. of a sterile 1% azolitmin solution and proceed as directed under "Plate Method" for the respective milk product. Acidifying organisms show a red color.

Determinations for acidifiers are of value for milk, sweetened condensed milk and milk powder. In the case of milk the presence of large numbers is indicative of contamination from unclean utensils or inadequate cooling on the farm. In sweetened condensed milk they may give rise to early bacterial thickening. In milk powder they are usually present in small numbers only, especially in the case of drum-dried powders.

Proteolytic Types.—The approximate proportion of proteolytic bacteria present may be determined by picking colonies from agar plates into tubes of sterile skimmilk and noting whether or not proteolysis occurs. All colonies on a plate or all from a certain sector should be picked.

A direct plating may be made for these organisms by using beef infusion agar and adding .5 cc. sterile skimmilk[283] to each plate, or the casein agar of Frazier and Rupp,[284] and following the usual plate method. After incubation for 4 to 5 days at room temperature, flood the plates with dilute acid (10% hydrochloric acid). Those colonies which retain the clearing around them are true proteolyzers. These organisms digest the proteins and are capable of liquefying gelatin. Among this class of micro-organisms are some of the most troublesome species encountered in evaporated milk defects. They are usually the result of insanitary conditions of the factory equipment, such as unclean filling machines, milk pipes and pumps, etc. These organisms are spore-bearing and therefore very resistant to heat. Many of these species are anaerobes and require cultivating under anaerobic conditions. For directions to make anaerobic cultures see "Air Requirements" in succeeding paragraphs.

Gas Producers.—Prepare beef extract bouillon and add 2% sugar,—sucrose in the case of sweetened condensed milk, or lactose for evaporated milk, and milk powder. The bouillon is prepared according to the following formula:

Beef extract	3 grams
Peptone	5 "
Sugar	20 "
Distilled water	1 liter

Reaction—pH 6.8 to 7.0

Heat in flowing steam to dissolve ingredients, adjust the reaction if necessary, filter through absorbent cotton, and tube in 10 cc. amounts with an inverted vial in each test tube. Sterilize at 15 lb. pressure for 15 minutes.

The product to be tested is usually added in 1 cc. amounts. If it is desired to know the approximate density of the gas formers, the amounts of inoculum used may be 10 cc., 1.0 cc., 0.1 cc., 0.01 cc. and etc. With 10 cc. inoculations the amount of sugar bouillon should be not less than 20 cc. The tubes are incubated at 37°C. and examined for gas in the inverted tubes after 48 hours incubation. For a standard procedure for the detection of organisms of the colon group, which ferment lactose with gas production, the reader is referred to the provisional method in "Standard Methods of Milk Analysis."[278]

The medium recommended (brilliant green lactose peptone bile) is particularly suited to the examination of milk and such products as contain acid-producing bacteria, which interfere with the development of gas formers in ordinary lactose bouillon.

Yeasts Capable of Causing Bloats.—Sucrose-fermenting yeasts capable of growth and gas production in high concentrations of sucrose are always a potential source of trouble in the manufacture of sweetened condensed milk. As a routine check for detection of possible contamination with these types, it is recommended that sample cans be incubated at 37°C. for extended periods. If "swells" develop the milk should be plated on standard nutrient agar (or beef infusion agar) to which 30% sucrose has been added before sterilization.

As a further check on the condition of sweetened condensed milk immediately after manufacture it is suggested that enrichment in 30% sucrose bouillon be used, noting the presence or absence of gas production after incubation for two days at 37°C., followed by plating on 30% sucrose agar. The presence of yeasts capable of fermenting this concentration of sugar with gas production is the signal for a careful study of sources of contamination in the plant, which must include taking samples at various stages in manufacture and their subjection to the same test. Whether or not the types isolated are capable of causing "swells" must be determined by direct inoculation into cans of fresh product.

The direct microscopic count on both the fresh product and that which has been incubated for enrichment purposes may be useful in the examination for yeasts. This would of necessity be supplemented by cultural methods to determine the type of yeasts present.

Gas producing organisms are responsible for such defects as bloats of sweetened condensed milk and of evaporated milk. When present in the milk as it arrives at the factory they are usually of the E. coli type which indicates fecal contamination. Bloats of sweetened condensed milk are almost invariably due to yeasts capable of fermenting sucrose in highly concentrated solution. Bloats of evaporated milk generally are caused by sporing putrefactive species that are anaerobes.

Yeasts and Molds.—Make agar plates as directed under "Plate Method" using standard extract agar or beef infusion agar to which has been added 2% dextrose, and adjust the reaction to pH 3.5 to 4.0 with a sterile 10% solution of tartaric acid. The medium should be sterilized in 100 cc. quantities and the amount of tartaric acid necessary to add per 100 cc. can be determined electrometrically or colorimetrically. For the latter method the indicator brom phenol blue is used, giving a yellowish green color at pH 3.5. The details of the test are the same as given under "Acid Reaction" above.

Potato dextrose agar as used for yeast and mold counts on butter[283] may also be used in the examination of condensed and evaporated milks.

Thermophiles.—These organisms are of importance in raw milk and may play a part in the keeping quality of evaporated milk. Their numbers may be determined by the plate method using the following special agar:[282]

Beef extract	3	grams
Peptone	5	"
Dextrose	1	"
Bacto Tryptophane Broth	2.5	"
Bacto Yeast Extract	1	"
Agar	15	"
Distilled water to make	1	liter
Reaction pH 7.0 to 7.2		

The preparation of the plates is the same as for the total plate count on milk, except that 15 cc. of agar is used per plate. Incubate at 55°C. for 48 hours and provide humidity with large dishes of water.

Investigation of Causes of Specific Defects.—In the study of defects due to micro-organisms it is usually helpful to isolate in pure culture the predominating type present. If it has been responsible for the trouble its reinoculation into the normal product will reproduce the defect. If the investigation is to be of tangible value to the factory it must also include the determination of the source of the causative organism, or of the defect in the process of manufacture that permits its entry or growth.

Studies of this nature are facilitated by the use of suitable enrichment media such as beef bouillon containing sucrose for sweetened condensed milk defects, usually 2% sugar for bacterial development and 30% sugar for the yeasts capable of causing "bloats." Litmus milk, and bouillon containing 2% lactose or dextrose are useful as enrichment media for plain condensed and evaporated milk organisms. Inoculation for enrichment purposes, combined with the simultaneous plating of the original defective product, followed if necessary by the plating of the inoculated litmus milk or bouillon culture, constitutes a complete and usually dependable method for the isolation of the causative organism. Direct microscopic examination of the original material should be used to obtain an idea of the types of organisms present and their relative numbers.

Air Requirements of Bacteria.—Successful determination of the causes of specific bacterial defects requires also consideration of the air requirements of the organisms responsible. The bacterial defects of sweetened condensed milk are generally due to organisms that either require, prefer, or tolerate the presence of oxygen. Thus bloats are almost invariably caused by yeasts, buttons are due to molds, and bacterial thickening appears to be brought about by organisms which, similar to yeasts and molds, grow well in the presence of free oxygen. The same is true also of a variety of bacteria responsible for diverse bacterial defects in unsweetened condensed milk and evaporated milk, such as sour curd, bitter curd, bitter flavor without curd formation, fishy flavor, etc.

In the case of bloats of evaporated milk, however, the bacteria responsible are usually of the anaerobic type; that is, they grow only in the absence of free oxygen. These bloats are most often due to butyric acid and putrefactive species and their isolation and study require anaerobic methods.

There are various methods available for producing and maintaining anaerobic cultural conditions. Where laboratory facilities are limited, as is generally the case in the average factory, the use of deep agar tubes such as the Veillon tube, or of oxygen-absorbing chemicals such as alkaline pyrogallol, has been found most serviceable and is recommended as described below:

The Veillon Tube Method.—Use glass tubing of 1 cm. bore and 9 in. long. Tightly plug one end with a rubber stopper. Fill the tube with agar to a depth of about 5 inches. Plug the open end with non-absorbent cotton and sterilize. After cooling to about 45°C., inoculate the still liquid agar in a manner that will diffuse the inoculum as much as possible throughout the tube. Allow agar to solidify and place the tubes into incubator at 37°C.

In order to reach the colonies for isolation, reinoculation, and further study, remove the agar plug from the tube by withdrawing the rubber stopper. Allow the plug to drop into a sterile petri dish. The desired colonies in any part of the agar plug may then be reached readily with the platinum needle.

Alkaline Pyrogallol Method.—Use dry commercial pyrogallic acid and sodium hydroxide sticks in the proportion of 1 gram of pyrogallol and 0.4 gram of sodium hydroxide per 100 cc. of air space in the desiccator.

Place 50 grams of dry pyrogallol into the bottom part of a 5 liter desiccator. Cover the ground flange or rim of the desiccator and the corresponding flange of the cover with a mixture consisting of half paraffine and half bees' wax. Place the plates or tubes into the desiccator in such position as to make possible the addition of water and sodium hydroxide to the pyrogallol in the bottom part. Now add with pipette 100 cc. of water and then drop 20 grams of the sodium hydroxide into the bottom part and quickly close the desiccator by putting the cover in place. Turn the cover so as to secure a perfect seal and apply three large screw clamps. Place the desiccator into the incubator at 37°C.

In case a desiccator cover equipped with glass stop-cock for rubber tube connection is available, it is of advantage to extend a rubber tube from the underside of the stop-cock connection into the pyrogallol in the bottom part of the desiccator and close the desiccator before the water and alkali are added. In this case, after sealing the apparatus airtight, the sodium hydroxide may be dissolved in the water to be added. The desiccator is then first evacuated and the sodium hydroxide solution is introduced through the stop-cock.

Classification of Species.—The technique and methods used for the study of cultural and morphological characteristics leading to the classification of individual species are fully described in standard manuals on bacteriology.

CHAPTER XXXVIII

DEFINITIONS AND STANDARDS FOR MILK, CONDENSED MILK AND DRIED MILK PRODUCTS

U. S. Federal Standards in Force January 1, 1934[276]

1. Milk is the whole, fresh, clean lacteal secretion obtained by the complete milking of one or more healthy cows, properly fed and kept, excluding that obtained within 15 days before and 5 days after calving, or such longer period as may be necessary to render the milk practically colostrum free.

2. Pasteurized milk is milk that has been subjected to a temperature not lower than 145°F. for not less than 30 minutes, after which it is promptly cooled to 50° or lower.

3. Homogenized milk is milk that has been mechanically treated in such a manner as to alter its physical properties, with particular reference to the condition and appearance of the fat globules.

4. Skimmed milk is milk from which substantially all of the milk fat has been removed.

5. Buttermilk is the product that remains when fat is removed from milk or cream, sweet or sour, in the process of churning. It contains not less than 8.5 per cent of milk solids not fat.

6. Cultured buttermilk is the product obtained by souring pasteurized skimmed, or partially skimmed, milk by means of a suitable culture of lactic bacteria. It contains not less than 8.5 per cent of milk solids not fat.

7. Goat's milk, ewe's milk, etc., are the fresh, clean lacteal secretions, free from colostrum, obtained by the complete milking of healthy animals other than cows, properly fed and kept, and conform in name to the species of animal from which they are obtained.

8. Evaporated milk is the product resulting from the evaporation of a considerable portion of the water from milk, or from milk with adjustment, if necessary, of the ratio of fat to non-fat solids by the addition or by the abstraction of cream. It con-

tains not less than 7.8 per cent of milk fat, nor less than 25.5 per cent of total milk solids; provided, however, that the sum of the percentages of milk fat and total milk solids be not less than 33.7.

9. Sweetened condensed milk is the product resulting from the evaporation of a considerable portion of the water from milk to which sugar (sucrose)* has been added. It contains not less than 28 per cent of total milk solids, and not less than 8 per cent of milk fat.

10. Evaporated skimmed milk is the product resulting from the evaporation of a considerable portion of the water from skimmed milk, and contains not less than 20 per cent of milk solids.

11. Sweetened condensed skimmed milk is the product resulting from the evaporation of a considerable portion of the water from skimmed milk to which sugar (sucrose)* has been added. It contains not less than 24 per cent of milk solids.

12. Dried milk is the product resulting from the removal of water from milk, and contains not less than 26 per cent of milk fat, and not more than 5 per cent of moisture.

13. Dried skimmed milk is the product resulting from the removal of water from skimmed milk, and contains not more than 5 per cent of moisture.

14. Malted milk is the product made by combining whole milk with the liquid separated from a mash of ground barley malt and wheat flour, with or without the addition of sodium chloride, sodium bicarbonate, and potassium bicarbonate, in such a manner as to secure the full enzymic action of the malt extract, and by removing water. The resulting product contains not less than 7.5 per cent of butterfat and not more than 3.5 per cent of moisture.

15. Cream, sweet cream, is that portion of milk, rich in milk fat, which rises to the surface of milk on standing or is separated from it by centrifugal force. It is fresh and clean. It contains not less than 18 per cent of milk fat and not more than 0.2 per cent of acid-reacting substances, calculated in terms of lactic acid.

16. Whipping cream is cream which contains not less than 30 per cent of milk fat.

17. Homogenized cream is cream that has been mechan-

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*or dextrose.

ically treated in such a manner as to alter its physical properties, with particular reference to the condition and appearance of the fat globules.

18. Evaporated cream, clotted cream, is cream from which a considerable portion of water has been evaporated.

Paragraphs 9 and 11 in the above Definitions and Standards were amended to include the use of dextrose in sweetened condensed milk and sweetened condensed skimmilk, by ruling of the United States Department of Agriculture[43] December 26, 1930, which reads as follows:

"The use of pure refined corn sugar as an ingredient in the packing, preparation and processing of any article of food in which sugar is a recognized element need not be declared upon the label of any such product."

Table 62.—Condensed Milk Standards in Great Britain

	Total Milk Solids Per Cent	Fat Per Cent
Full-cream, unsweetened (evaporated milk)	31.0	9.0
Full-cream, sweetened (sweetened condensed milk)	31.0	9.2
Skim, unsweetened	20.0	...
Skim, sweetened	26.0	...

Table 63.—U. S. Tariff on Condensed and Dried Milks, Lactose and Casein*

Date Effective	Condensed Milk			Milk Sugar	Milk Powder				Casein
	Cents per Pound				Cents per Pound			Per Cent	
	Sweetened	Unsweetened	Other	Cents per Pound	Skim	Whole	Cream	Malted	Cents per Pound
Aug. 6, 1909	2.0	2.0	2.0	5.0	......	......	......	......	......
Oct. 4, 1913	Free	Free	Free	Free	......	......	......	......	......
May 28, 1921	2.0	2.0	2.0	Free	......	......	......	......	......
Sept. 22, 1922	1½	1.0	1⅜	50 per cent	1½	3.0	7.0	20.0	2½
June 18, 1930	2.75	1.8	2.53	50 per cent	3.0	6 1/12	12 ⅛	35.0	5½

*Pirtle, T. R., A Handbook of Dairy Statistics, U. S. Dept. of Agr. B. A. E. 1933.

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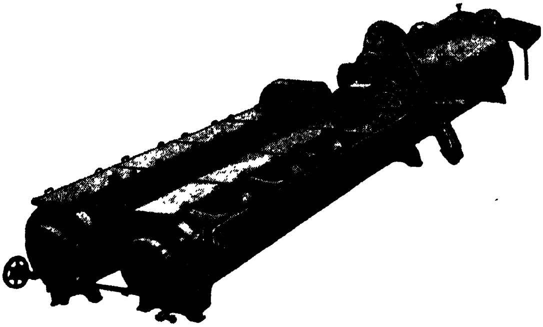

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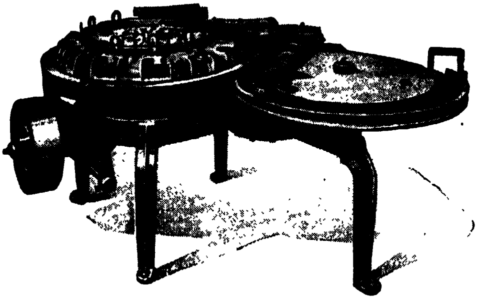

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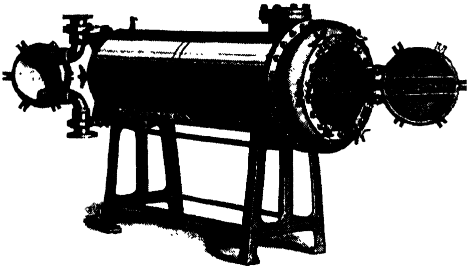

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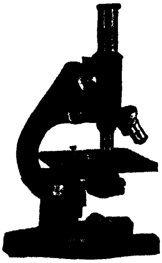

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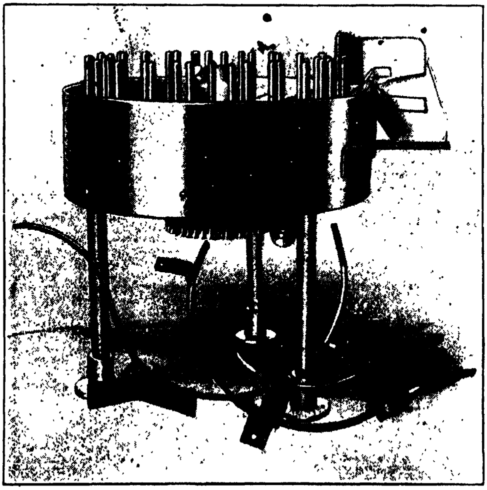

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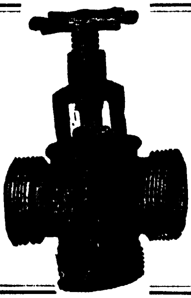

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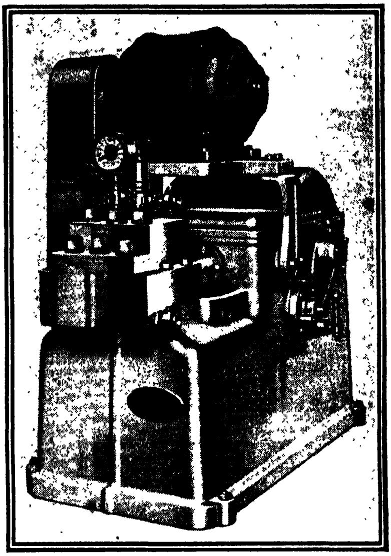

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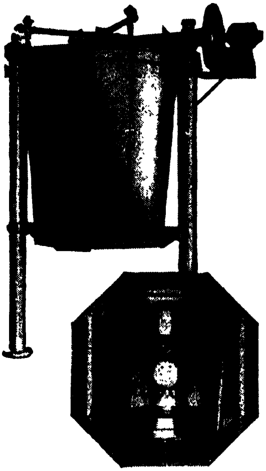

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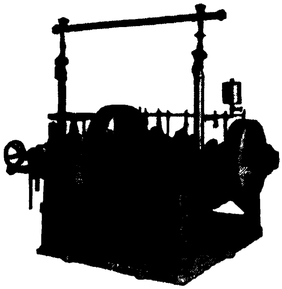

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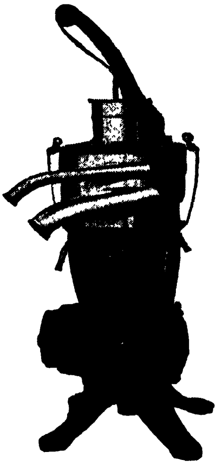

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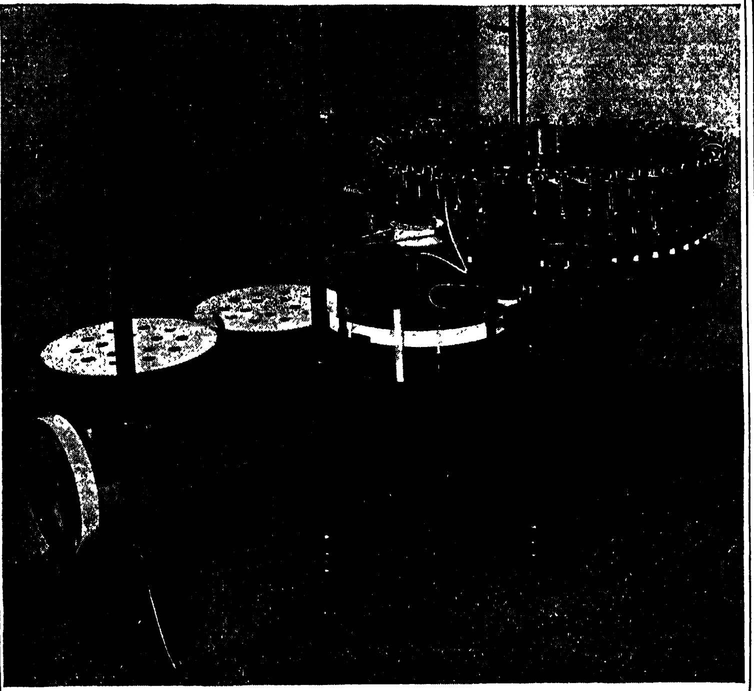

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Straight Edges
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C. DOERING & SON INC.

1375-85 W. LAKE ST., CHICAGO

BETTER PACKAGED BUTTER

makes better business

If you wait for it to come it may go to more aggressive manufacturers selling better formed, full weight, attractive butter prints.

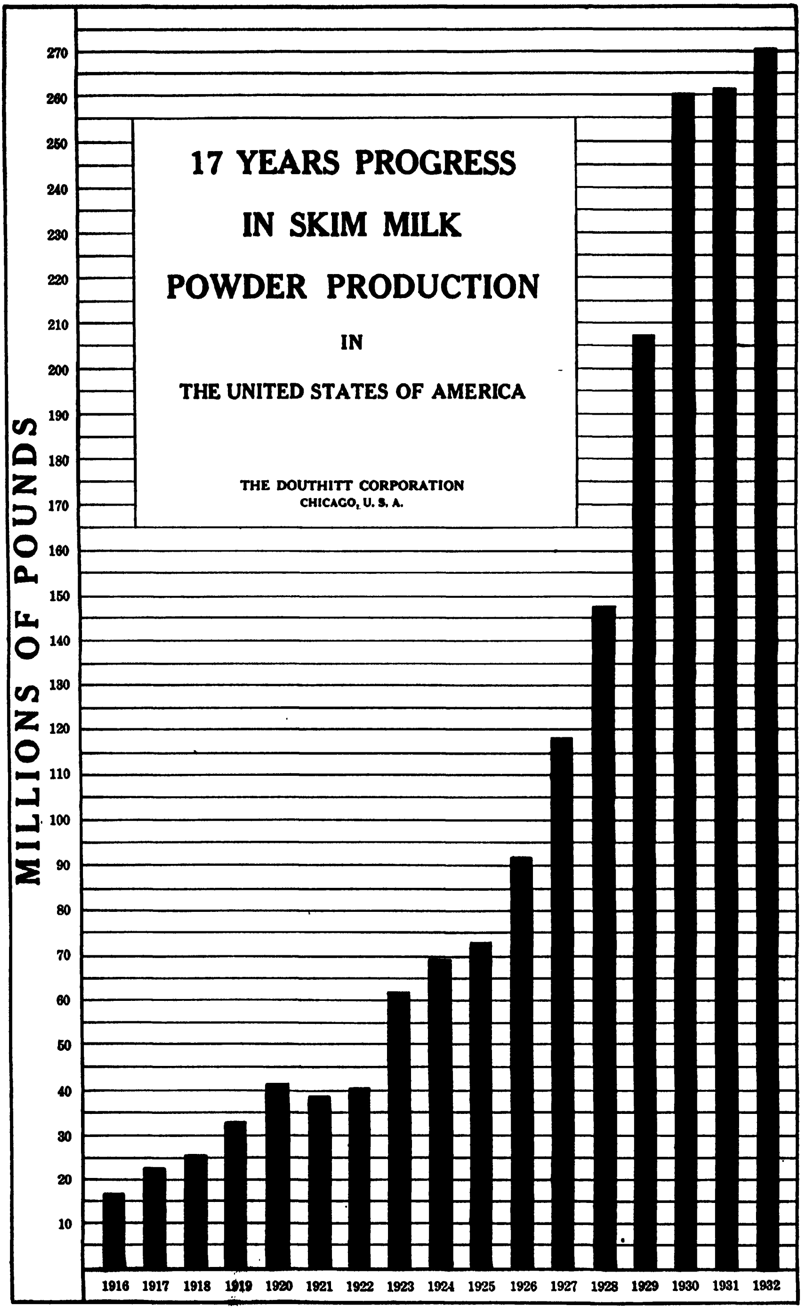
Modern housewives demand PACKAGED butter because they know it is clean—sanitary—its quality unwavering. Give them a trade-marked product and—once satisfied as to quality—they will ask for your butter again and again.

All sizes and shapes are at your disposal with DOERING BUTTER PRINTERS made in sizes to print 200 to 5000 lbs. per hour.

Doering

BUTTER PRINT MACHINES

C. DOERING & SONS, INC.
1377 W. Lake St. - Chicago, Ill.


17 YEARS PROGRESS
IN SKIM MILK
POWDER PRODUCTION
IN
THE UNITED STATES OF AMERICA
THE DOUTHITT CORPORATION
CHICAGO, U. S. A.
MILLIONS OF POUNDS
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
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30
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1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932

DOUTHITT

107

Drying Plants Built by
The Douthitt Organization

43 Douthitt Roller Process Drying Plants for Milk.

58 Douthitt Gray-Jensen Spray Process Drying Plants for Milk.

6 Douthitt Gray-Jensen Spray Process Drying Plants for other food products.

The
Douthitt
SPRAY PROCESS
Corporation
DRYING PLANTS
CHICAGO ILLINOIS
U.S.A.

DOUTHITT

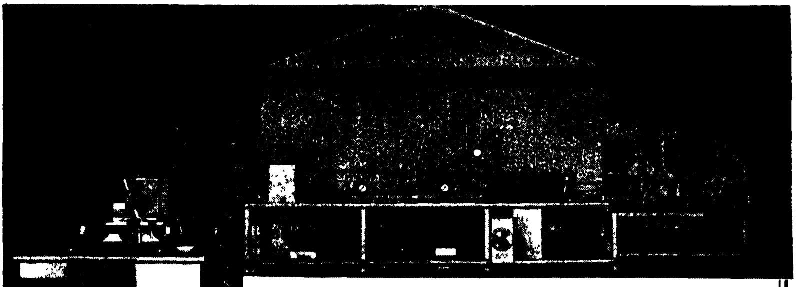
Condensing and Vacuum Equipment for Milk Evaporators

Even for ordinary low vacuums (25″ to 26″), Elliott steam jet ejectors have advantages of reduced installation costs, simplified piping arrangement, and low maintenance costs over reciprocating vacuum pumps. For vacuums of 28″ and up, substantial savings in steam economy can also be achieved.

It will pay you to investigate the possibilities of Elliott steam jet ejectors and condensing equipment. The wide experience of Elliott engineers in applying ejector vacuum equipment is at your service.

In addition to ejectors and condensers, Elliott Company manufactures a line of power plant equipment including steam turbines and engines, motors and generators, feed water heaters and deaerators, and many accessory items such as strainers, grease extractors, separators, etc.

ELLIOTT COMPANY
Pittsburgh, Pa.
Heat Transfer Department, Jeannette, Pa.
District Offices in Principal Cities



L-P Can Washer Layouts

L-P *Standard Automatic* Straightaway Can Washers turn out *clean, sterile, bone-dry* cans at lowest operating cost. When installed according to layouts recommended by L-P Engineers (a specialized service offered to any prospective purchaser) these washers permit *all* Receiving Room operations to be handled by one man at the rate of 20,000 lbs. of milk per hour—two men, 40,000 lbs.—three men, 60,000 lbs. There are 14 L-P Can Washer models . . . one for every type and size of plant.

L-P Ball and Socket Chain CONVEYORS *for Cans and Cartons*
Outstanding Features: Unusually *long life* (due to tough Manganese Steel Chain). *Adaptability* to plant conditions (due to complete flexibility of ball and socket joints). *Rugged*, durable construction. Will handle cartons without soiling them.

The Lathrop-Paulson Co.
Can Washers and Conveyors
2459 W. 48th Street Chicago, Illinois

COMPLETE CLEANING SERVICE

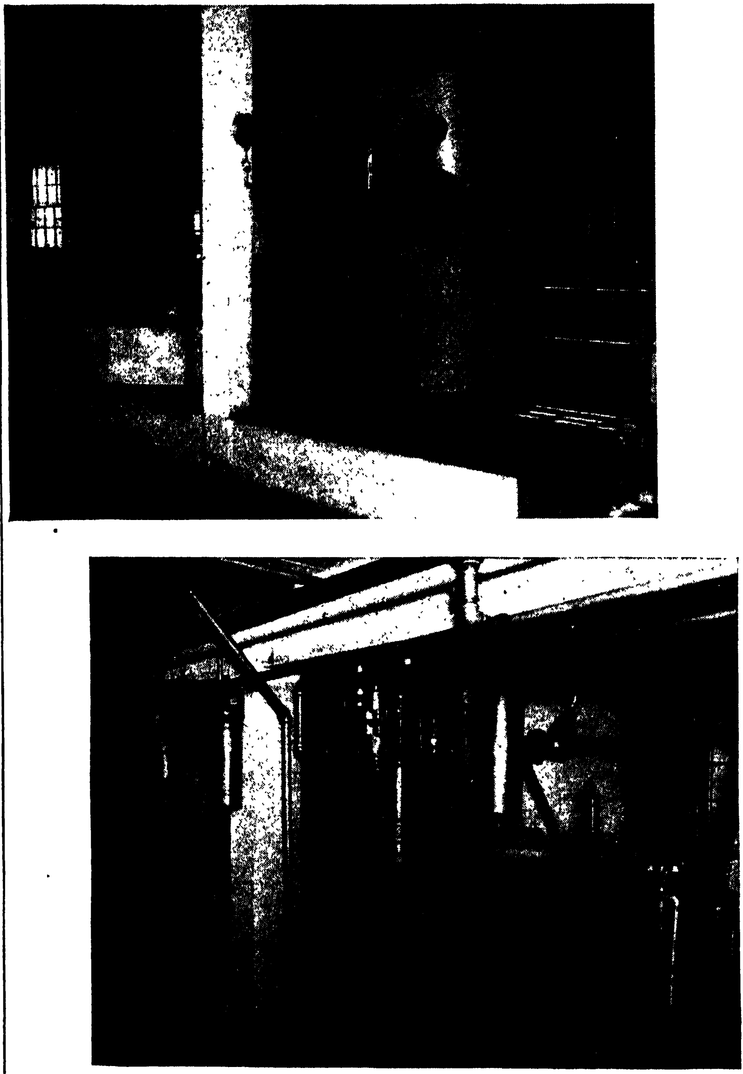
Whatever your cleaning problem may be there is a Wyandotte Product which is scientifically made to insure efficient, economical, and sanitary work. And the accumulated experience of years of contact with the dairy industry is available to you without obligation.

This is the complete cleaning service which is yours when you buy Wyandotte. In addition, you are assured of prompt shipment from jobber's or storage stocks which are conveniently located to supply you.

Order from Your Supply Man
or write for detailed
information.

Wyandotte
Cleaner and Cleanser

The J. B. Ford Company, Wyandotte, Mich.

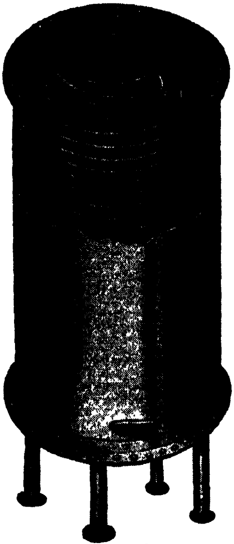


Complete Installation of Harris High Speed Milk Evaporator

ARTHUR HARRIS & CO., CHICAGO, ILL.

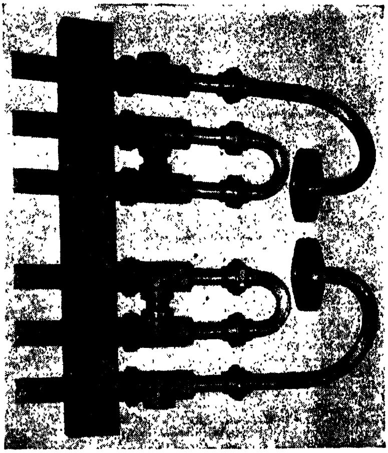
VACUUM PANS WITH BAROMETRIC OR JET CONDENSERS

HARRIS COOLERS FOR SWEETENED CONDENSED MILK



Patented

Steel coil cooler with reversed counter current water flow for efficient and economical operation.



Fine crystal formation and smooth velvety texture—counter current single tube cooler with full floating stainless steel tubes and removable return bends.

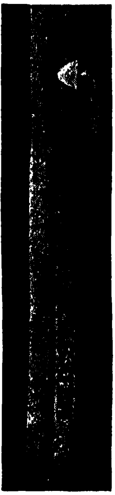
Steam turbine driven fresh milk circulating pump for preheating units. Clean oil free exhaust steam is utilized in preheater.

ARTHUR HARRIS & COMPANY

Engineers, Designers & Builders of Condensed Milk Machinery

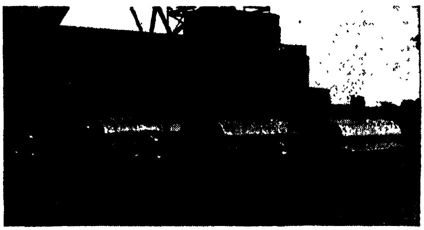
210-218 N. Curtis Street **Chicago, Illinois**

Now the Dairy Industry Can Afford to Use Much More STAINLESS STEEL



Stainless Cladding ⅛" | Mild Steel ⅝" A. S. M. E. Test Bar—actual dimensions taken from pressure vessel head.

Borg-Warner Corporation, through its subsidiary—Ingersoll Steel & Disc Company—has perfected a product of priceless value to the Dairy Industry. A new steel known as IngAclad used in the construction of Tanks, Vats and other equipment, provides stainless steel service at approximately half the material cost of solid stainless.



Fleet of IngAclad Tank Trucks, 1500 to 2500 gallons capacity, built for Greencastle Milk Transportation Co.

INGACLAD

(Trade Mark Reg.)

STAINLESS-CLAD STEEL

consists of a cladding of finest quality of stainless steel, inseparably welded onto a base of mild steel. The weld or bond between the two metals is formed in the ingot. When rolled into sheets and plates of any thickness, IngAclad retains its uniform stainless cladding and may be formed, drawn, spun, beaded, brazed, soldered and fabricated to meet every requirement.

Milk storage tank (1600 gallons) installed for Libby, McNeill & Libby, at Patterson, Calif.

Strictly Sanitary

IngAclad gives complete resistance to rust, corrosion, acids and fumes, and positively assures easy maintenance of strict sanitation and cleanliness. Its use in the Dairy Industry gives constant protection against discoloration or any other change in the character, flavor or odor of your products.

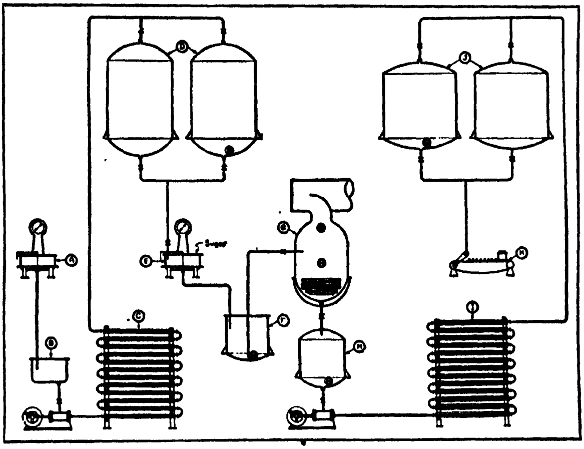
Ask for Free Catalog-Folder and references of actual installations

INGERSOLL STEEL & DISC CO. 310 S. Michigan Ave. CHICAGO, ILL.

(*A Division of Borg-Warner Corporation*)
Plants: Chicago, Illinois, and New Castle, Indiana

Recommended Materials of Construction in Evaporated or Sweetened Condensed Milk Equipment

(See Chapter "METALS IN DAIRY EQUIPMENT")



A. Weigh Tank	Inconel or Pure Nickel
B. Pump Reservoir	Inconel or Pure Nickel
C. Fluid Milk Cooler	Nickel or Inconel Tubes
D. Fluid Milk Storage	Pure Nickel or Inconel Nickel-Clad Steel or Inconel-Clad Steel
E. Weigh Tank	Inconel or Pure Nickel
F. Hot Well	Inconel or Inconel-clad Steel
G. Evaporator	Body—Inconel-Clad Steel or Nickel-Clad Steel Coils or Tubes—Nickel or Inconel
H. Drop Tank	Pure Nickel or Inconel Nickel-Clad Steel or Inconel-Clad Steel
I. Condensed or Evaporated Milk Cooler	Nickel for Condensed Milk Inconel Tubes for either product
J. Condensed or Evaporated Milk Storage Tanks	Nickel-Clad Steel or Inconel-Clad Steel
K. Filling Machine	Nickel or Inconel parts
Sanitary Piping	Pure Nickel, except between F and G. Inconel may be used for all piping.

Available Publications sent on request:—

"Metals and Condensed Milk—Corrosion of Metals in Manufacture of Evaporated and Sweetened Condensed Milk"

"Bulletin TS-1—The Resistance of Pure Nickel and Inconel to Corrosion by Milk"

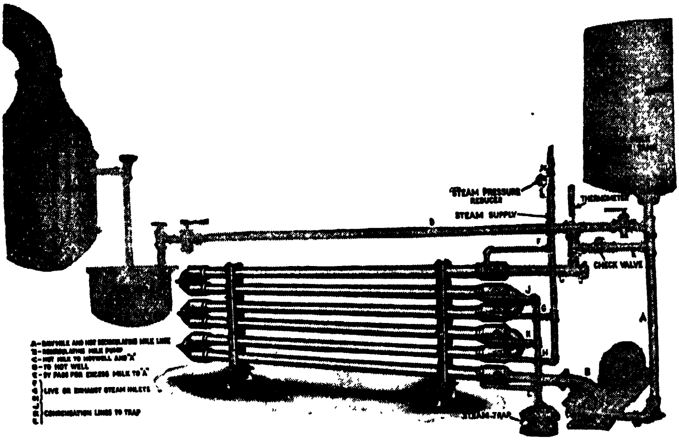
"Bulletin T-7 —Properties and Uses of Inconel"

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York, N. Y.

Jensen Full-Floating Preheater

SAVES 20%

Time—Fuel—Operating Cost


STEAM PRESSURE REDUCER
STEAM SUPPLY
THERMOMETER
CHECK VALVE
STEAM TRAP
A—RAW MILK AND HOT RECIRCULATING MILK LINE
B—RECIRCULATING MILK PUMP
C—HOT MILK TO HOTWELL AND "A"
D—TO HOT WELL
E—BY PASS FOR EXCESS MILK TO "A"
F G H LIVE OR EXHAUST STEAM INLETS
J K L CONDENSATION LINES TO TRAP
A
B
C
D
E
F
G
H
J
K

Live steam when condensing in milk while being heated in a hot well increases moisture 15%, which must be later removed while the product is in the pan. A Jensen Full-Floating Preheater:

1. Produces whiter product.
2. Prevents burning, even up to 210° F.
3. Saves 20% operating time.
4. Effects corresponding steam saving.
5. Saves 20% condenser water (no small item in itself.)

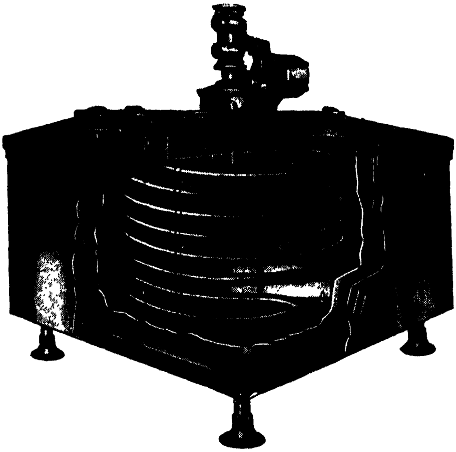
Jensen Preheated milk pleases consumers with its improved body, texture, and color. Details on request.

Write for bulletin 38A.

Jensen Creamery Machinery Company
Bloomfield, N. J. **Chicago, Ill.**
Oakland, Calif.

Sweetened condensed milk

without sand or grit



Jensen Vertical Coil Sweetened Condensed Milk Coolers

produce a finished product free of sand, grit and mould. The machine furnishes a balanced relationship between the baffle surface, cooling surface and agitation. Various coil speeds are furnished through using our Maxum-Viscotrol Drive.

Air cannot be incorporated but instead is constantly removed. Mould and other contaminations are thereby prevented.

Body, viscosity, and keeping quality satisfactory to your consumers are produced by Jensen Vertical Coil Equipment.

Ask for bulletin 29D.

Jensen Creamery Machinery Company

Bloomfield, N. J. **Chicago, Ill.**
Oakland, Calif.

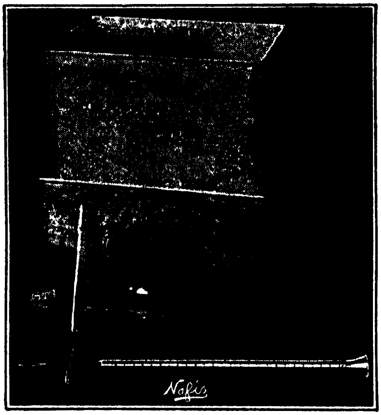
NAFIS SCIENTIFIC TEST APPARATUS

For the production of high quality condensed and powdered milk.

We Suggest—

THE NAFIS REDUCTASE TEST No. 640

for selecting raw milk according to bacteria content. Use it as a valuable guide in determining the sources of good milks and as a basis for field work. The test is simple and easy to make and economical in cost.



THE NAFIS AUTOMATIC ACIDITY TEST No. 620

as a simple, rapid method for determining the percentage of acidity in the raw or finished product. It is very useful in controlling various manufacturing processes.

Nafis Scientific Test Apparatus is sold by all leading dairy supply houses.

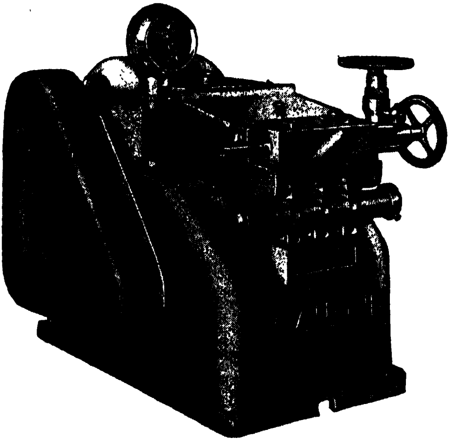
A full line of Babcock Milk and Cream Test Bottles and all other Test and Control Glassware for the Dairy Industry is stocked by them.

Kimble-Nafis Dairy Division of

KIMBLE GLASS CO.

111 N. Canal St. Chicago, Ill.

THE MANTON-GAULIN TWO-STAGE HOMOGENIZER



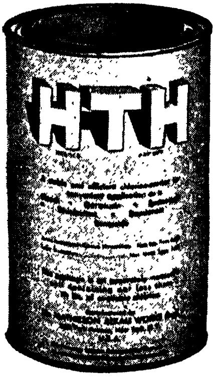
The Gaulin Homogenizer is built for continuous operation under extreme pressures, yet will produce remarkably fine and uniform fat globules at low pressures — The Two-Stage Valve is a real advantage—Real sanitation made possible through modern construction — Forged Stainless Steel Cylinder Block, Removable Manifold, Removable Stuffing Boxes, Shock proof Gauge.

Send for descriptive catalogue—no obligation.

MANTON-GAULIN MFG. CO., INC.
ST. JOHNSBURY, VT.

HTH Kills Bacteria Quickly!

Safe — Efficient — Economical!



H T H is a true calcium hypochlorite, stable and easily soluble. Over 65% of the weight of each 4-lb. can is active chlorine that will rapidly destroy bacteria when used in the solutions recommended. H T H is the *least expensive* reliable source of hypochlorite solutions you can buy. Used in hundreds of creameries, dairies and dairy product plants.

- And for milk producers—**HTH-15**

H T H-15 makes balanced *sodium* hypochlorite solutions when added direct to water. Packed in 1 and 8-lb. cans with a handy measuring spoon for convenient use by milk producers, farm dairymen, etc. A spoonful makes up to 8 gallons of bactericidal rinse that's safe on equipment.

THE MATHIESON ALKALI WORKS (INC.)
NEW YORK — CHICAGO — PHILADELPHIA — CINCINNATI — CHARLOTTE

John B. Meyenberg
Inventor Evaporated Milk

MEYENBERG
Milk Products Co.

Manufacturers

of

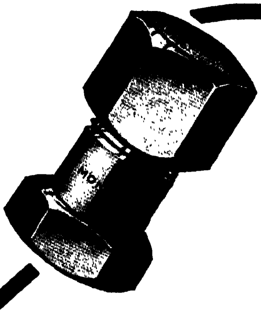
Evaporated and Condensed Milk

for

Domestic and Export Trade

General Office:
208-9 Salinas Natl. Bank
Bldg., Salinas, California
Factories:
Soledad, California
Ripon, California

MONARCH MILK POWDERING SPRAYS



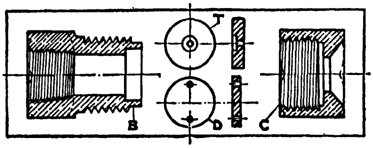
Monarch Fig. 621 MP milk powdering sprays have been standard equipment in a great many milk powdering plants for a number of years. Fine quality atomitization and comparatively long wear make these sprays highly desirable for this type of work.

Parts T and D, subject to wearing action, are made of a material of diamond-like hardness consequently being highly resistant to wear, assuring uniformly fine powder over a long period of time.

Standard Tip Sizes

Tip No.	No. of Slots	SIZE OF ORIFICE IN		
		M/M	Drill No.	Dec. In.
79	2	⅜	79	.0145
76	2	½	76	.0200
76	4	½	76	.0200
72	2	41/64	72	.0250
72	4	41/64	72	.0250
69	2	¾	69	.0292
69	4	¾	69	.0292
58	2	1	58	.0420
58	4	1	58	.0420

Write for descriptive literature.



MONARCH MFG. WORKS, Inc.
2725 E. Westmoreland Street
PHILADELPHIA, PA.

REDUCE your Cleaning Costs

. . . enjoy care-free, positive sanitation!

FREE-RINSING
CONCENTRATED
. . no fillers
. . no waste
SAFE on tinned glass lined and other surfaces
EFFECTIVE . . . softens casein, slime
UNIFORM...always standard quality

Oakite Service Men, cleaning specialists, are located in all the principal producing and distributing dairy sections of the United States.

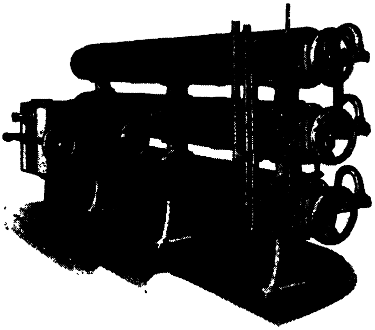
You can depend on OAKITE materials taking care of your evaporator, separator, holding vat, pipe line and vacuum pan cleaning at low cost. 25 years' experience making dairy cleaners backs our guarantee of absolute uniformity of material. Each grain is effective, concentrated cleaner that assures the same safe, thorough results day after day. Write for details. No obligation.

OAKITE PRODUCTS, INC.
22 Thames St. New York, N. Y.

OAKITE
Industrial Cleaning Materials and Methods

Silkeborg

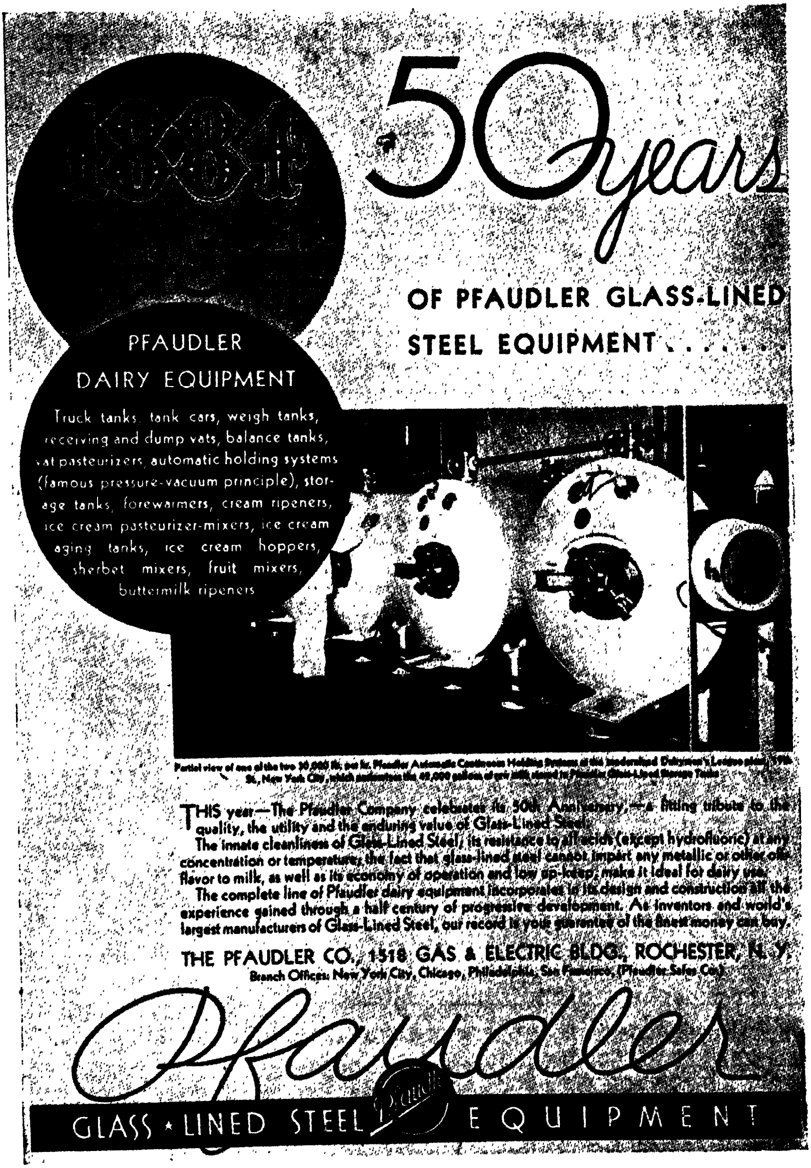
Complete MILK POWDER PLANTS



Complete Dairy Plants, *Stassanisers*, Plate Pasteurisers, Combined Churn and Butter Workers

CODES USED:
A. B. C. Code 4th & 5th Edition,
Bentley's Code, Lieber's, Code,
Private Code

SILKEBORG MASKINFABRIK
Zeuthen & Larsen
SILKEBORG, DENMARK
Cables: Maskinfabriken



50 years OF PFAUDLER GLASS-LINED STEEL EQUIPMENT . . . . .

PFAUDLER
DAIRY EQUIPMENT

Truck tanks, tank cars, weigh tanks, receiving and dump vats, balance tanks, vat pasteurizers, automatic holding systems (famous pressure-vacuum principle), storage tanks, forewarmers, cream ripeners, ice cream pasteurizer-mixers, ice cream aging tanks, ice cream hoppers, sherbet mixers, fruit mixers, buttermilk ripeners

Partial view of one of the two 30,000 lb. per hr. Pfaudler Automatic Continuous Holding Systems at the modernized Dairymen's League plant, [illegible] St., New York City, which [illegible] the 45,000 gallons of raw milk stored in Pfaudler Glass-Lined Storage Tanks

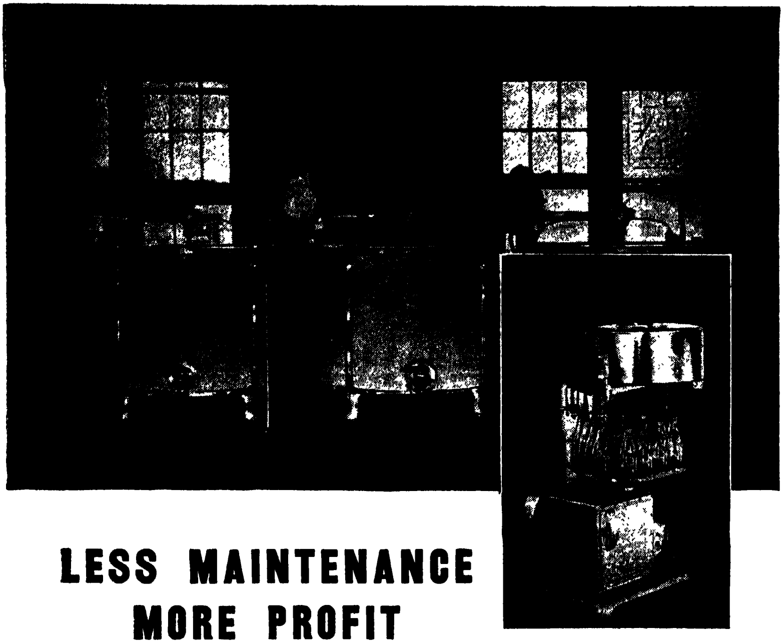
THIS year—The Pfaudler Company celebrates its 50th Anniversary,—a fitting tribute to the quality, the utility and the enduring value of Glass-Lined Steel.

The innate cleanliness of Glass-Lined Steel, its resistance to all acids (except hydrofluoric) at any concentration or temperature, the fact that glass-lined steel cannot impart any metallic or other off-flavor to milk, as well as its economy of operation and low up-keep, make it ideal for dairy use.

The complete line of Pfaudler dairy equipment incorporates in its design and construction all the experience gained through a half century of progressive development. As inventors and world's largest manufacturers of Glass-Lined Steel, our record is your guarantee of the finest money can buy.

THE PFAUDLER CO., 1518 GAS & ELECTRIC BLDG., ROCHESTER, N. Y.
Branch Offices: New York City, Chicago, Philadelphia, San Francisco, (Pfaudler Sales Co.)

Pfaudler
GLASS-LINED STEEL EQUIPMENT



LESS MAINTENANCE
MORE PROFIT

when equipment is made from safe, stainless **ENDURO**

Stainless ENDURO has banished all worry over equipment maintenance and product spoilage due to corrosion. For ENDURO resists the corrosive action of all dairy products; retaining its lustrous and sanitary appearance for the life of the equipment. And being a solid steel, stainless all the way through, it never requires patching or relining. • ENDURO is recognized as the preferred metal for pasteurizers, holding tanks, coolers, filling machines, piping, cheese vats, etc., by leading dairies, by dairy equipment manufacturers and by authorities on metals which come in contact with dairy products. All equipment manufacturers now are supplying this life-time metal. • There is a wealth of data available relative to the advantages of ENDURO which every dairy executive should have. Write Republic for this information today.

ENDURO
REPUBLIC'S PERFECTED
STAINLESS STEEL

CENTRAL ALLOY DIVISION MASSILLON, OHIO
REPUBLIC STEEL CORPORATION
GENERAL OFFICES: YOUNGSTOWN, OHIO

Rogers Vacuum Pans and Spray Drying Equipment

Fully Described in Chapters
VI, XXIV *and* XXX

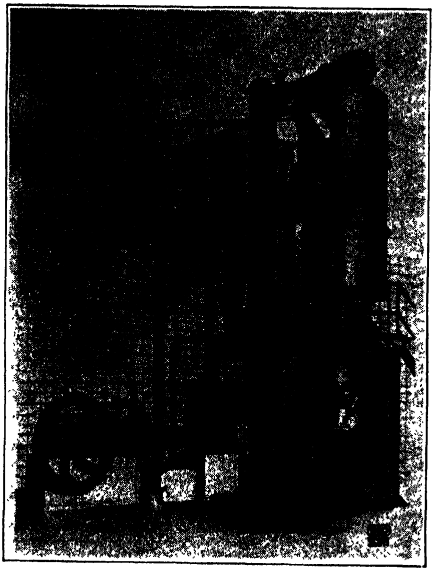
Rogers Condensing and Drying Equipment used by Leading Manufacturers throughout the World

Let Us Help Solve
Your Problems

C. E. ROGERS CO.
Detroit, Michigan

SCOTT

MILK PROCESSING PLANT



COMPLETE
EQUIPMENT
for
CONDENSED
EVAPORATED
and
DRIED MILK
FACTORIES

CONDENSING PLANT
SUPERIMPOSED TYPE—STAINLESS
STEEL CONTACT THROUGHOUT

FOR ALL MILK PRODUCTS

"SCOTT" PATENT FORCED CIRCULATION CONDENSER
"SCOTT" PATENT HIGH VACUUM CONDENSED MILK COOLER
"SCOTT" PATENT HIGH VACUUM BAND DRYER
MILK SUPERHEATERS SUGAR PANS ETC., ETC.

GEORGE SCOTT & SON (London) Ltd.
ARTILLERY HOUSE, ARTILLERY ROW,
LONDON S. W. I. ENG.

PROVEN PERFORMANCE IN THE MILK INDUSTRY

LAPIDOLITH	The most economical and lasting chemical treatment for making concrete floors wearproof and dustproof.
MARVELWITE "T"	A chemical enamel for interior surfaces capable of resisting severe chemical conditions and intense heat, and retain its whiteness without discoloration.
CEMCOAT	An interior and exterior coating in wide use among dairies and creameries.

MANUFACTURERS

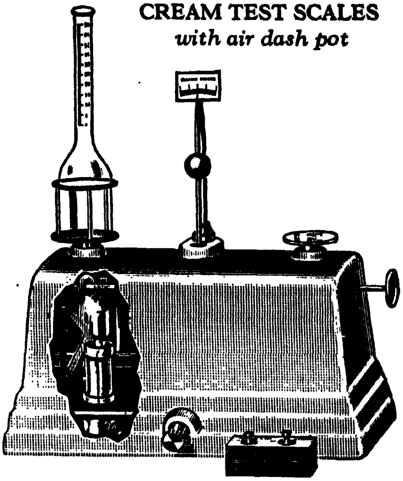
L. SONNEBORN SONS, INC.

88 LEXINGTON AVENUE NEW YORK CITY

Offices in Principal Cities

CREAM TEST SCALES

with air dash pot



No Levelling Screws. Bottles Tared and Scale Levelled in One Operation by means of Thumb Screw

WEIGHING

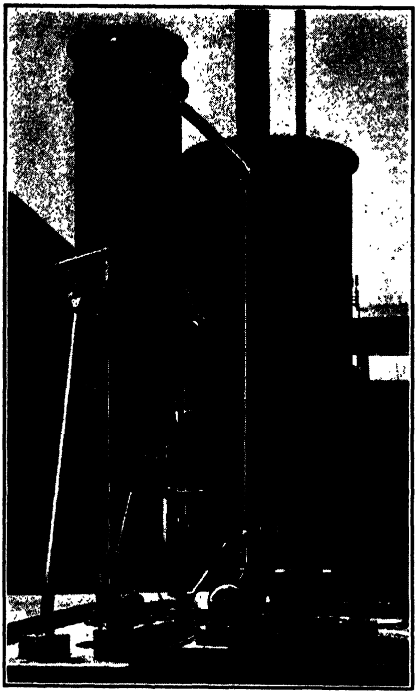
with an Air Dash Pot Scale is the last point of efficiency. It will eliminate the undue swinging of the pans and automatically come, almost immediately, to a cushioned stop. Operators report a saving of 25% to 50% time when using Torsion Air Dash Pot Scales. There is no delicate or intricate mechanism, nothing to get out of order on the Air Dash Pot, it needs no lubrication, contains no oil or grease.

Send for Bulletin No. 513

THE TORSION BALANCE CO.

Sales Offices:
92 Reade Street, New York City
228 N. La Salle Street, Chicago
576 Mission Street, San Francisco

Factory: 147-153 Eighth Street,
Jersey City, N. J.



Zaremba Double Effect Evaporators operate at low temperatures in both bodies and require less steam than other types. Designed with outside steam chests for easy cleaning.

Zaremba Single Effect Evaporators are built with outside steam chests of entirely sanitary construction. Easy to operate and easy to clean.

ZAREMBA

RECOMPRESSION MILK EVAPORATORS...

Zaremba Patented Recompression Evaporators include special designs exactly suitable for every condition met in the concentration of whole milk, skim milk, buttermilk, whey and other milk food products. Particularly adapted to delicate food products and other solutions sensitive to heat. Deliver maximum quality at reduced manufacturing cost. No "burning on" or burned flavor. Save 50% to 70% steam and condensing water. We will appreciate your inquiries.

ZAREMBA COMPANY

506 CROSBY BUILDING, BUFFALO, N. Y.

DELHI UNIVERSITY LIBRARY.

Books drawn from the Library by Members of the Court, Members of the Teaching Staffs of the University constituent Colleges may be retained not longer than *one month.*

Books drawn by Students on Roll, and by others who have obtained special permission may be retained not longer than *two weeks.*

Numbers of periodicals when issued are due back one week after being taken out.

A fine of one anna will be charged each day for each volume or number that is overdue.

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